PRODUCTION

HANDBOOK

Edited by

L. P. ALFORD, M.E., Dr. Eng.

Late Professor and Chairman of the Department of Administrative Engineering, New York University

AND

JOHN R. BANGS, M.E.

Professor and Head of the Department of Administrative Engineering, Cornell University

Staff Editor

GEORGE E. HAGEMANN, B.S. in M.E.

NEW YORK

THE RONALD PRESS COMPANY

1944

CONTRIBUTING AND CONSULTING EDITORS

HAROLD VINTON COES
Vice President, Ford, Bacon & Davis, Inc.; Past-President, American Society of Mechanical Engineers

WILLIAM B. CORNELL
Professor of Management and Chairman of the Department of Management and Industrial Relations, New York University

CARLOS DE ZAFRA
Industrial Consultant

CARL F. DIETZ
President, Lamson Corporation

RALPH E. FLANDERS
President, Jones & Lamson Machine Co.; Past-President, American Society of Mechanical Engineers

GLENN GARDINER
Vice President, Forstmann Woolen Co.

WILLIAM H. GESELL
Vice-President, Lehn & Fink Products Corporation

LILLIAN M. GILBRETH
Professor of Management, Purdue University

R. E. GILLMOR
President, Sperry Gyroscope Company, Inc.

JOHN H. GOSS
President, Scovill Manufacturing Company

E. GRIFFITHS
Director, Headquarters Manufacturing Engineering Department, Westinghouse Electric & Manufacturing Company

J. E. HANNUM
Dean of Engineering, Alabama Polytechnic Institute

C. D. HART
Superintendent of Lead Covered Cable and Station Apparatus Shops, Baltimore Works, Western Electric Company, Incorporated

GEORGE B. HEDDENDORF
Educational Department, International Business Machines Corporation

ANDREW B. HOLMSTROM
Vice President and General Manager, Abrasive Division, Norton Company

OSCAR E. JOHNSON
Director of Materials Handling, General Cable Corporation

THOMAS D. JOLLY
Vice President, Engineering and Purchasing, Aluminum Company of America

THOMAS ROY JONES
President, American Type Founders, Inc.

JOSEPH M. JURAN
Manufacturing Engineer, Western Electric Company, Incorporated

H. C. KELLER
Engineering Manager, Lamson Corporation

Y W. KELLY
Director of Personnel, Olin Corporation

BERT T. KENT
Consulting Engineer

XTER S. KIMBALL
Professor of Mechanical Engineering, Emeritus, Cornell University; Past-President, American Society of Mechanical Engineers

A S. KNOWLES
Dean and Director, School of Business Administration, Rhode Island State College

IEODORE LANG
Professor of Accounting, New York University; Editor, "Cost Accountants' Handbook"

F. LINCOLN
President, The Lincoln Electric Company

P. LOSELY
S. D. Leidesdorf & Co.

EWART M. LOWRY
Director of Industrial Relations, The Procter & Gamble Company

OBERT H. LUCKENBACH
Director of Safety, Edward G. Budd Manufacturing Co.

CHARLES WALTER LYTLE
Associate Professor of Industrial Engineering, New York University

ENNETH MACGRATH
General Manager, Eclipse-Pioneer Division, Bendix Aviation Corporation

OSEPH MANUELE
Director of Quality Control, Westinghouse Electric & Manufacturing Company

LFRED MARCHEV
President, Republic Aviation Corporation

GEORGE W. MASON
President, Nash-Kelvinator Corporation

HAROLD B. MAYNARD
President, Methods Engineering Council

JOHN F. MEE
Assistant Professor of Management and Director of Personnel Placement Bureau, University of Indiana

WILLIAM N. MITCHELL
Professor of Business Organization, School of Business, University of Chicago; Management Consultant, McKinsey, Kearney and Company

ALLAN H. MOGENSEN
Industrial Consultant

L. C. MORROW
Editor, "Factory Management and Maintenance"

ROBERT LEE MORROW
Consulting Engineer; Lecturer, Department of Administrative Engineering, New York University

TER L. TANN
mmander U.S.N.R.; Formerly Planning and Control Engineer, Far-
el-Birmingham Co., Inc.
F. TINSLEY
resident, Crompton & Knowles Loom Works
IP S. VAN WYCK
irector, Bureau of Training, War Manpower Commission
UY VIA
Supervisor of Training, Newport News Shipbuilding and Dry Dock Company
WRENCE W. WALLACE
Vice President, The Trundle Engineering Company
E. WALTERS
Principal, McKinsey & Co.
CARLTON WARD, JR.
President, Fairchild Engine and Airplane Corporation
IOMAS A. WATSON
Associate Professor in Mechanical Arts, University of California at Los Angeles
EONARD B. WEISS
Plant Superintendent, Plastics Moulding Corporation
ENDALL C. WHITE
Assistant Professor of Administrative Engineering, Cornell University
A. M. WIBEL
Vice President in Charge of Purchasing, Nash-Kelvinator Corporation
BALDWIN M. WOODS
Professor of Mechanical Engineering and Director of University Extension, University of California
JOHN YOUNGER
Chairman, Department of Industrial Engineering, The Ohio State University

PREFACE

In the field of manufacturing production this Handbook is unique. It covers intensively the problems of directing the men, materials, and machines of a manufacturing establishment. It deals with more effective turning out of product; living up to time schedules; working under the requirements of budgets and costs which it is the production man's job to meet if the business is to forge ahead of competition and make money.

To these ends the volume offers a presentation of this planning and control of the production process which is nowhere else obtainable in Handbook form.

The Production Handbook has been designed for practical daily use by the manufacturing men for whom it is intended; and to be readily understandable and helpful to many others besides those with specialized technical background. Both principle and method have been weighed for fundamental engineering soundness, dependability for important decisions where production is concerned, and usefulness as a source of information for all who have occasion to understand production methods and processes. In short, the aim has been to make available a Production Handbook for everyone in manufacturing, which no one in manufacturing can well afford to be without.

An important group of users also kept in mind is that of the oncoming younger men in manufacturing. For them there is no other handbook source for the information presented here. The volume should be invaluable for training production men.

The character of treatment in the Handbook consciously follows its design. With every topic the endeavor has been to set forth the guiding principles, and to show how efforts must be organized, how to establish a functioning department or procedure, and finally how to work out the technical details of specific problems. Examples and working illustrations are liberally used to give acquaintance with the practice of well-known companies. Some of the subjects are in their nature unavoidably technical and mathematical. Endeavor has been made to make them as simple and understandable as possible.

In structural plan the Production Handbook follows the lines laid out by Dr. L. P. Alford as Editor. It incorporates his earlier experience as

Editor of both *Management's Handbook* and the *Cost and Productic Handbook*, and was the last undertaking of a distinguished career . engineer, manufacturing executive, editor and educator, in which] received many professional honors, and which extended from early pe sonal acquaintance with the pioneering work of Taylor and of Gantt - a final wide vision of the tremendous war production achievements mad possible by the principles to which he gave a lifetime of service Although Dr. Alford did not live to see its publication, the Productio Handbook is built on the foundation that he laid.

For its completion a most fortunate choice was made in the selectio as Editor of John R. Bangs, Professor and Head of the Department c Administrative Engineering in Cornell University. Although under hea pressure of wartime responsibility as an executive of a large manufact ing company, he has been tireless in personal scrutiny of material goi into the Handbook, and seeing that it was supported by examples recent applications and reviewed by suitable authority. George E. Hag mann, as Staff Editor, has assisted Professor Bangs and carried throu the myriad technical details of the Handbook. Both Professor Bangs an Mr. Hagemann were long and intimately acquainted with Dr. Alford an his work, and a generous part of the achievement in completing a mos difficult task is due to their ability and skill.

For evidence of the authority of what is presented in the Production Handbook it is hardly necessary to go further than perusal of the list o Contributing and Consulting Editors, with the positions they occupy in American industry. The Publishers cannot pay too great a tribute to the labor of service performed by these men. All carrying heavy loads an wartime responsibilities, they have nevertheless given precious time an energy to review of the sections of the Handbook. They have made constructive criticism, strengthened methods of treatment, contribute data from their own experience and in many cases enlisted the aid o specialists in their organizations in verifying technical detail. Thoug no handbook can hope to attain perfection in every respect, it would b difficult to do more than they have done to assure a handbook on th whole accurately representative of the best practice.

While no section of the Production Handbook has been produced by one individual, the work of a number of the Contributing Editors in particular fields merits special recognition. Such contributions have been those of William N. Mitchell, in *Production Planning and Control*; Donald G. Clark, in *Purchasing*; Asa S. Knowles, in *Storeskeeping* and in *Merit Rating*; Robert Lee Morrow, in *Time Study and Operation Analysis*; David B. Porter, in *Motion Study—Work Simplification*; Carlos de Zafra, in *Inspection* and in *Tools, Jigs and Fixtures*; A. I. Peterson, in

ality Control; Kendall C. White, in *Plant Layout*; Paul T. Norton, Jr., d Erik Oberg, in *Machinery*; Joseph A. Piacitelli, in *Materials Han-ng*; Julius C. G. Seidl, in *Job Estimating*; Charles W. Lytle, in *Job aluation* and in *Wage Plans;* H. P. Losely, in *Plant Maintenance*; eodore Lang, in *Manufacturing Costs*; John F. Mee, in *Factory Budg-s*; and Roy W. Kelly, Robert H. Luckenbach and Leonard B. Weiss, in *ant Personnel.* Through their special interests and experience, these itors have made available a wealth of valuable information, and in a mber of cases their contributions were considered by exacting critics be among the best treatments in their fields.

The sources of information and material in the Production Handbook legion. They include standard books, articles, reports, professional iety proceedings, data of industrial companies, information from ipment manufacturers and professional data of individual engineers d production men. The Editors and Publishers take this opportunity express their appreciation for the cooperation and courtesy every-ere extended, and have endeavored to give specific credit to all such urces of information on modern production.

THE RONALD PRESS COMPANY
Publishers

CONTENTS

PRODUCTION HANDBOOK

SECTION 1

PLANT ORGANIZATION

CONTENTS

Organization Charts and Manuals

Analysis of Organization and Procedures

SECTION 1

PLANT ORGANIZATION

SCOPE OF ORGANIZATION.—The subject of organization, in its broadest definition, includes (1) the persons who man a company, (2) the respective places which they occupy, (3) the range of authority and responsibility which they individually exercise, (4) the framework of relations through one another, and (5) the mechanisms through which they operate and coordinate their activities in the enterprise. It is upon the basis of persons, positions, authority, contacts, operations, and coordination that successful production work is carried on.

THE ELEMENT OF COMMON PURPOSE.—Whenever two or more persons unite to attain a common purpose an organization is formed. **Organization, the framework** within which individuals unite, is an essential in reaching toward a common objective. In spite of this fact, successful and adequately functioning organizations are rare. Most organizations are short-lived and those that have had long-continued success are exceptions. In this Handbook consideration of organization is limited to the types in manufacturing enterprises.

Organization Structure

STRUCTURE OF ORGANIZATION.—The structure of industrial organization under usual conditions of operation is the result of growth. Concerns start in a small way and gradually expand. One or two men have authority and all responsibilities at first and, by force of circumstances, operation centers in and around them. As growth continues, this method of operation and control becomes ineffective and it is evident that a **planned structure of organization** is needed. To satisfy this necessity, the various functions of the enterprise should be clearly outlined, specified in writing, and charted. This is a process of design carried on without regard to the personnel or individuals involved. When the organization is planned or designed to accomplish desired results, individuals can be selected to fill the various positions. As a rule these men are found within the existing personnel. Thus the requirements of minimum operating friction, high man-hour productivity, and sound industrial relations are more often met in concerns already operating than in new enterprises. But an organization soon degenerates under mechanical and routinized operation and hence must be revamped at intervals to prevent stagnation or stunted growth.

ASPECTS OF INDUSTRIAL ORGANIZATION.—There are a number of aspects from which an industrial organization can be viewed. It may be considered from the standpoint of:

1. The activities involved.
2. The functions under which these activities are to be carried on rather than the scattered activities themselves.
3. Titles of positions to which these functions are assigned.
4. Personnel, the particular individuals who occupy positions indicated by the titles.
5. Coordination, that is, joining together the activities for a common purpose, and timing the performances of the several individuals to whom they have been assigned.
6. According to combinations of two or more of these considerations.

Another aspect of industrial organization deals with the physical arrangement of the departments and production centers in a factory, that is, with the factory layout.

DEFINITIONS.—Some confusion exists in the concepts of administration, management and organization.

Administration, sometimes called the "function of direction," has been defined as:

"The force which lays down the object for which an organization and its management are to strive and the broad policies under which they are to operate." (Schulze, T.S. Bul., vol. IV)

Definitions of management present it as an economic activity in a manufacturing organization:

"Art and science of preparing, organizing, and directing human effort applied to control the forces and to utilize the materials of nature for the benefit of man." (Management Division, A.S.M.E.)

"That phase of an undertaking which relates to (a) making policies, (b) developing programs, (c) setting standards, (d) applying programs to financial, physical, and human resources, (e) maintaining plant, equipment, supervisory, labor, and clerical forces at maximum efficiency; and which by the foregoing means and also by means of current direction, conference and inspection aims to assure the delivery of commodities and/or services according to program, within a scheduled time and at minimum cost." (Deacon)

Definitions sometimes present management as a personnel group:

"That group of executives and supervisors who, in any industrial establishment, make decisions for, and give orders to, employees or workers." (Alford, Mgt. Eng., vol. 52)

Definitions of organization in some instances support the idea of planning or designing the functions; in other cases are directed to selection of personnel to execute those functions; and in still other cases combine these two concepts. The following definitions present both these ideas and concepts. Organization is:

"Division of work to be done into defined tasks and assignment of these tasks to individuals qualified by training and natural characteristics for their efficient accomplishment." (Alford)

"The laying out of the scope and limits of action of the various individuals and groups of individuals whose work is required for carrying on the objects of the establishment. It consists further of the

uniting of these individuals and groups of individuals in such a manner as to cooperate for the common good, harmoniously, promptly, and economically." (Diemer, Factory Organization and Management)

From the standpoint of the framework or structure which is capable of being designed, the following definition applies:

The structure, or design, of an organization involves determination of what functions or activities are needful to any purpose, and arranging them in groups to be assigned to individuals.

Oliver Sheldon (The Philosophy of Management) has presented one of the best summaries defining the various terms in relation to one another. He says:

Administration is the function in industry concerned in the determination of the corporate policy, the coordination of finance, production, and distribution, the settlement of the compass of the organization, and the ultimate control of the executive.

Management proper is the function in industry concerned in the execution of policy, within the limits set up by administration, and the employment of the organization for the particular objects set before it.

Organization is the process of so combining the work which individuals or groups have to perform with the faculties necessary for its execution that the duties so formed provide the best channels for the efficient, systematic, positive, and coordinated application of the available effort.

Organization is the formation of an effective machine; management, of an effective executive; administration, of an effective direction. Administration determines the organization; management uses it. Administration defines the goal; management strives toward it. Organization is the machine of management in its achievement of the ends determined by administration.

THE PURPOSE OF ORGANIZATION.—Organization concerns itself with the classification or grouping of the activities of an enterprise for purposes of administering them. Organization is to the business what the nervous system is to the human body. Its purpose is to send instructions (impulses) to the operating members and to receive and transmit to top management (the brain) information which will enable it to function intelligently (Rabbe, Mech. Eng., vol. 63).

There is a wide range of opinion regarding the relative importance of organization. One executive will claim that almost any type of organization will work so long as the right people are operating it. Other administrators lay great stress on organization charts, procedures, and techniques, and adapt the human factor to this framework. Perhaps a compromise between these two views is the best plan, giving due consideration to the human side of organization and using certain proved charts and guides, procedures and techniques.

Good management concerns itself with the development of people as well as the direction of things. Proper selection, training, and upgrading form the very basis of morale building, and morale can make or break an organization.

Policies and Organization

RELATION OF POLICIES AND ORGANIZATION.—A necessary preliminary to all activity in an industrial enterprise is a clear, complete statement of the object of the activity formulated as a policy

or set of instructions. In this connection an **industrial policy** can be thought of as a code or general rule which states the established procedure to follow in a recurring situation. Policies considered here are those set up by production executives as part of the managerial procedure of operating the plant to produce the product. A policy of this kind establishes objectives and formulates plans for achieving them. Thus all rules, regulations, and systems should be explicit expressions of formulated policies. **Determination of policies** is an important step; if they are wrong, the subsequent results may bring confusion and losses. Policies must be based on (1) thorough investigation and analysis, and (2) a full appreciation of consequences, both good and bad. **Adoption of a policy** requires on the part of managers both ability and courage, for fundamentally a policy at time of its adoption is intended to initiate a change, to improve conditions, to correct ineffectiveness, or to eliminate inefficiencies.

THE POLICY MANUAL.—The policy manual or "policy book" is a valuable management device, but one that is not widely used except for personnel relations. It can be employed for any one or all of the several kinds of policies found in a production organization—managerial or supervisory, long range, general, or departmental. Its advantages are: (1) it avoids misunderstandings, friction, lost motion and expense, for the policies are written down; (2) it facilitates a check on compliance; (3) it aids in indoctrinating or inculcating throughout the executive and supervisory personnel the principles and procedures necessary to put the policies into effect.

Mooney and Reiley (The Principles of Organization) emphasize the **importance of indoctrination** if freedom of action is to be secured in a production organization:

> Industrial indoctrination simply means thorough definition of the principles governing the industrial policy. It includes the application of the principles through line delegation of authority, the staff function, the duties and responsibilities of each in relation to the others, the place and purpose of rules and procedures and the comprehension of this doctrine throughout the organization.

POLICY ENFORCEMENT.—Inasmuch as a policy is a statement of procedure, of something to be done, and how to do it, it has within itself no force to bring results. **Executive action** is needed to make any policy effective. The stronger and more effective the leadership exerted, the greater the probability that policies will be adequately enforced and predetermined results realized. In other words, achievements in manufacturing enterprises come from decisions put into effect by the will of the one who is responsible for policy enforcement and who exercises leadership. It is a familiar saying that any institution is but the shadow of a man, of a creative mind, and that statement is particularly true of industrial plants.

Whatever an organization accomplishes by way of achievement or economic results depends upon the **quality of leadership** that organizes, directs, and manages the efforts of every individual, from president to laborer. A plant cannot attain sound objectives or achieve adequate results if its leaders are deficient in ethics, abilities, or volition. The capacity of an individual for leadership appears to be the net sum of all his powers.

Development of a Plan of Organization

DETERMINATION OF FUNDAMENTALS.—In setting up a plan of organization, the first step is the determination of the fundamentals that are to enter into the design, and their relationships. These fundamentals are: policies, authorities, responsibilities, and duties or activities. Policies have been presented in preceding paragraphs; authorities, responsibilities, and duties are discussed in those immediately following.

Authority.—The term authority may be defined as follows:

> In an organizational sense authority is the right of one person to require another person to perform certain duties.

Authority is the right to act, decide, and command. In a corporation it emanates from the stockholders, flows to the elected board of directors, whence it is delegated to designated persons who issue orders and instructions to subordinates. Authority may be classified as either (1) direct, or (2) delegated. Direct authority exists where the line between the issuer and acceptor is unbroken; delegated authority exists where an intermediate agency is between the issuer and acceptor.

Authority may have one or more of these aspects:

1. It may be formal, that is, conferred by law or delegated within an organization.
2. It may be functional or intrinsic, because it is based on special knowledge or skill.
3. It may be personal, that is, accorded because of seniority, popularity, or outstanding qualities of leadership.

While authority is the right to require performance of duties by another, nevertheless **authority rests upon the acceptance of the orders or instructions** by the person to whom they are addressed. Barnard (The Functions of the Executive) has this to say:

> The necessity of the assent of the individual to establish authority for him is inescapable. A person can and will accept a communication as authoritative only when four conditions simultaneously obtain: (1) he can and does understand the communication; (2) at the time of his decision he believes it is not inconsistent with the purpose of the organization; (3) at the time of his decision, he believes it to be compatible with his personal interest as a whole; and (4) he is able mentally and physically to comply with it.

Responsibility.—A clear conception of the significance of the term responsibility is presented in the following definition:

> In an organizational sense responsibility is accountability for the performance of assigned duties.

Responsibility is a moral attribute. It implies fulfilment of a task, duty, or obligation according to orders given or promises made. Authority is commonly delegated only to persons of proved responsibility.

Organizational design calls for setting up **limits of responsibility** for each activity and effort, otherwise shortcoming or failure cannot be traced to its source and cause. Executives of weak responsibility cannot

carry the burden of many simultaneous obligations, nor make the multitude of decisions necessary in the operation of an industrial concern. Barnard (The Functions of the Executive) supports this statement:

Executive positions (1) imply a complex morality, and (2) require a high capacity of responsibility, (3) under conditions of activity, necessitating (4) commensurate general and specific technical abilities as a moral factor—in addition there is required (5) the faculty of creating morals for others.

Duties.—The activities assigned to a person in an organization are best specified in the form of duties, a term which may be thus defined:

In an organizational sense the duties allotted to an individual are the activities he is required to perform because of place he occupies in the organization.

A duty is that which a person is bound by obligation to do. In a factory it is often called "a piece of work," a job, a task, or a work assignment. In an organizational sense it is a contribution to the goal or objective, and an organization can be thought of as a system of coordinated contributions, or a system of coordinated activities.

PRINCIPLES OF ORGANIZATION.—Coes (Mech. Eng., vol. 65) states that sound organization structure includes the following basic principles:

"1. Separation of the functions of the business, such as sales and distribution, production, purchasing and procurement, financial and accounting, engineering, research and development, and industrial relations.
2. Setting these line functions up with their logical subdivisions so there is no overlapping or conflict and so that no individual receives direct orders from more than one individual—his immediate superior. He may, however, receive aid and advice from staff officers or assistants.
3. Clean-cut distinction between line and staff functions and functional control.
4. Clean-cut specification of each management job in the entire management sequence at the several management levels, to avoid divided responsibility.
5. Suitable and adequate delegation of authority and responsibility for each member in the management sequence varied in accordance with the management level.
6. Selection for each position in the management sequence for each management level of the most suitable and competent individual without fear, favor, or political influence."

He further points out that a substantial portion of the problems that are brought to the consulting management engineer actually emanate from violation of the cardinal principles of organization, such as:

"1. Confusion between line and staff duties (staff officers giving orders to subordinates of line officers).
2. Overlapping authority (two or more executives having control of sections of the same business function).
3. Responsibility without adequate delegation of authority (failure to recognize that adequate authority must go along with responsibility if responsibility is to be discharged).
4. No clear definition of duties. This usually results in overlapping authority, confusion, and conflict.

5. Executives cut across organization lines of flow of authority in issuing orders. The result is confusion and lowered morale. A clean-cut, definite organization is the means for orderly transmission of orders from the top to the bottom and for a reverse flow of information to the top. Hence it is a communication system.
6. Executives do not know how to delegate authority or what authority to delegate, but they will delegate responsibility, because they fear someone will become more important than they are.
7. Responsibility and authority are frequently assigned to an individual by executives because they like him regardless of whether he is competent, through training, skill, experience, and character, to fill the position; probably the wrong man is chosen for the job.
8. No clear-cut philosophy of management."

PRODUCTION ORGANIZATION DESIGN.—Production organization structure recognizes: (1) levels of authority, and (2) degrees of responsibility. The **line of authority** (line of command, or line of instruction) goes down from a higher to a lower level of authority. The **line of response** (line of performance, or line of accountability) comes up from a lower to a higher level of authority. These lines are also called **lines of communication,** and may be used to ask questions directed up or down the lines. In addition to these principal lines there is an expert function in the functional, or expert staff.

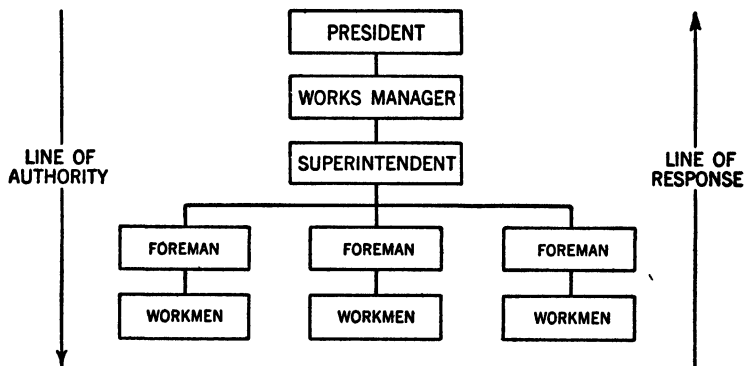



FIG. 1. Lines of Authority and Response in an Industrial Organization

A typical line of production authority is shown in Fig. 1 wherein titular positions are indicated as president, works manager, superintendent, foreman, workmen, giving five levels of authority. This number of levels is seldom exceeded except in very large organizations. The arrow at the left of diagram indicates the flow of authority and issuing of orders from the president down, level by level, until the workmen are reached. The arrow at the right indicates the line of response whereby reports and returns flow upward from workmen to whatever level these reports are directed. This line of response should be open for workmen to send suggestions, make complaints, and ask for adjustment of grievances, in such a way that these communications will reach the level of

authority and responsibility at which action can be taken. These lines of communication hold the organization together, and make a coordinated operating unit. They make possible the enforcement of policies and execution of orders with economy and dispatch.

Methods, procedures, and techniques of communication are an important factor in carrying on an industrial organization, and their excellence and effectiveness of use mean much to the efficiency of organizational performance. In this connection Barnard (The Functions of the Executive) says:

> In an exhaustive theory of organization, communication would occupy a central place, because the structure, extensiveness, and scope of organization are almost entirely determined by communication techniques.

Certain **controlling factors** are essential to frictionless operation of organizational lines of communication. Barnard recognizes seven subfactors:

1. The channels of communication should be definitely known.
2. A definite, formal channel of communication is required to every member of an organization.
3. The line of communication must be as direct or short as possible.
4. The complete line of communication should usually be used.
5. The competence of the persons serving as communication centers, that is, officers, supervisory heads, must be adequate.
6. The line of communication should not be interrupted during the time when the organization is to function.
7. Every communication transmitted along the line of communication should be authenticated.

There are many variations from the simple, typical lines of authority and response diagrammed in Fig. 1.

Typical degrees of responsibility of the operating organization, and general duties assigned to the several positions, are indicated in Fig. 2. This diagram shows the degrees of responsibility devolving upon the individuals at several levels of authority and also, in its lower part, the general duties attached to each of the indicated positions.

WORK DIVISION IN PRODUCTION ORGANIZATION.—Work division is the foundation of the approach to determine the relation of duties to be performed and the selection of individuals to whom duties are to be assigned in a production organization. Assignment of

Degree of Responsibility	First	Second	Third	Fourth	Fifth
Level of Position	President	Works Manager	Superintendent	Foreman	Workmen
Range of Duties	Administrative Policies General Management	Managerial Policies Managerial Control	Operating Control General Control of Production	Detail Control of Production	Performance of an Assigned Job

Fig. 2. Degrees of Responsibility and Corresponding Duties in an Industrial Organization

separate duties is necessary because of: (1) volume or amount of work to be done in an industrial plant; (2) differences in nature, capability and skill of men; (3) range of knowledge required in an organization, which is so vast that one individual can command only a fraction of it.

Although **work division** is the foundation of organization, there are limitations beyond which it should not be carried. The major limitations are: (1) No advantage is gained by subdividing work so minutely that the resulting task is less than that which a man can perform when working continuously. (2) Technology and custom make it impractical to subdivide certain kinds of work, although the influence of these factors is subject to change. (3) Subdivision must not be carried to the point of organic subdivision.

Walker lists **seven organic functions** of an industrial enterprise, stating that they are found in every productive enterprise and that they dictate major elements of manufacturing organization. He also relates these functions to the executives who exercise them.

Function	Executive in Charge
Control	General Manager
Design	Chief Engineer Chief Designer Chemist
Equipment	Plant Engineer Master Mechanic
Material	Purchasing Agent Storeskeepers Works Manager
Operation	Superintendent General Foreman
Sales	Sales Manager Treasurer
Comparison	Controller Chief Accountant

Process of Devolution.—The process of transferring authority and responsibility in an organization is one of devolution. The manager, when his duties become so numerous and pressing that he cannot properly attend to them all, delegates certain of them to another. Upon this assistant devolves the responsibility for certain assigned acts. If transfer of executive work takes place, adequate authority is delegated at same time that responsibility is shifted, so that control may be had of all necessary means for doing the work.

COORDINATION IN ORGANIZATION CONTROL.—When duties and activities are subdivided and allotted throughout a production organization, means must be provided to have all of them performed, and all the product turned out, on time, that is, everything must be completed according to a predetermined schedule. This process of **timing activities and reuniting subdivided work** in a factory is called coordination. The mechanism, or normal routine, through which coordination is achieved is the system.

The necessity for timing the doing of work, or coordinating efforts, is apparent by observing a gang of men hauling on a rope, or moving

a heavy object. Members of group must pull together, or heave together, if the work is to be done. Otherwise their efforts are wasted. An even simpler illustration is that of two men carrying a table or bench. They must lift together, and walk in step in same direction, if they are to move the piece of furniture from one place to another.

Coordination means to combine activity into a consistent and harmonious action. It is exhibited in highest degree of perfection in the functioning of the human body. Coordination of the kind which exists between mind and muscles of the human body is ideal for an industrial organization. The highest form of coordination in industry is that in which an entire group consciously accepts the objective and policies laid down by the leader, and consciously acquiesces in disciplines which are necessary to achieve the purpose. This type of coordination is possible only in a carefully selected, well-trained organization.

Barnard (The Functions of the Executive) lays emphasis on the willingness of persons to contribute their efforts, as an indispensable factor in the successful operation of organization. All of the components and forces of organization must work in harmony and unison. Activities must be kept in balance and properly timed at each level of authority.

Coordination in factory operation is obtained by various mechanisms. One of the most widely used is the system of Gantt charts. The principle of the Gantt chart is to show a comparison between promises and performance in such a definite way that failure to perform is sharply

Function	Human Body	Business as a Whole	Manufacturing	Selling
Direction	Brain and Sixth Sense	Executive Heads, "Assistants to" Executive Heads	Works Manager	Sales Manager
Expert Advice	Five Senses	Professional Auditors, Appraisers, Consulting Engineers, Lawyers, Patent Attorneys	Industrial Engineers, Research and Development Engineers	Marketing Specialist
Control and Coordination	Cerebellum	Controller, Financial Control	Production and Planning Engineers	Sales Planning and Control
Service and Facilitation	Involuntary Organs	Service Departments	Maintenance, Purchasing, Personnel	Sales Promotion and Advertising
Performance	Voluntary Organs	Manufacturing and Selling	Operating Departments, Workers	Sales Department, Salesmen

Fig. 3. Functions of Organization and Their Assignment, as Compared with the Functioning of the Human Body (C. E. Knoeppel)

brought to the attention of the one who is responsible. It seems to have a **dynamic ability to compel action.** Gantt applied this device to

1. Record the schedule of work ahead for a department or plant.
2. Record machine performance.
3. Record man performance.
4. Show the progress of work through a department or plant.

IDEAL FOR AN INDUSTRIAL ORGANIZATION.—An ideal industrial organization would be one that functioned as perfectly as does a **normal, healthy human body** (see Fig. 3). Another apt comparison is to a well-trained and coordinated football team, knowing thoroughly every play and signal, quick to diagnose and offset opponents' tactics, snapping into action instantaneously, and running every play with perfect teamwork.

Types of Organization

LINE ORGANIZATION.—Line of authority, or command, in its simple form is often referred to as the **military type of organization.** Its prototype is the organization of an army in its line or operational activities, apart from the present-day staff or planning and strategy functions, and probably it is as old as the combining of individuals for a joint activity, as for hunting or for war. In its simple, typical form it is not so extensively used as formerly in industry, except in small shops. In larger companies it is now usually combined with the functional or expert staff.

Because of the ancient origin and continued use of line organization, its relations are well defined. Henri Fayol, a French industrialist, laid down the **requirements for command,** or for the functioning of a line organization, as follows:

1. There must be a thorough knowledge of the working force.
2. Incompetence must be eliminated.
3. There must be a sound knowledge of the agreements between the management and its employees.
4. Those in authority must set a good example to the working force.
5. The organization must be periodically examined with the help of charts.

Features of Line Organization.—A business controlled under the line form of organization may act more quickly and effectively in changing its direction and policy than any other form of organization. Authority is passed down from the owners, through a board of directors to a general manager, to whom report the heads of the various departments. Each department in most instances is a complete self-sustaining unit, its head being responsible for the performance of its particular process, product, or function. This means that the foreman must (1) direct its techniques, (2) formulate the necessary work specifications, (3) sometimes purchase materials, (4) plan and schedule the work, (5) oversee the necessary materials handling, and (6) keep the necessary shop cost and production records. This same procedure would be repeated in all other departments with complete control centered in each head, subject only to the will of the general manager. What little research, planning, or central record-keeping is absolutely required falls

upon the general manager. Fig. 1 is a partial presentation of such a plan, in diagrammatic form.

The line organization is very stable and ideas and orders travel strictly according to the line of authority (see Fig. 2). There is never any question as to who is boss. Each division, department, or section is under a supervisor or foreman who is completely responsible for the work of his unit, except for those particular items which the general manager reserves for his own attention. The only interrelationship between the various departments is such as the general manager may establish. In short, he must be in constant touch with all the details of the business, and make decisions constantly, based upon, and involving, these details. It is obvious that this plan of organization grows more unwieldy and inefficient the larger the company becomes.

Advantages and Disadvantages of Line Control.—The advantages and disadvantages of line control have been summarized briefly by Bangs as follows:

Advantages:

1. It is simple.
2. There is a clear-cut division of authority and responsibility.
3. It is extremely stable.
4. It makes for quick action.
5. Discipline is easily maintained.

Disadvantages:

1. The organization is rigid and inflexible.
2. Being an autocratic system, it may be operated on an arbitrary, opinionated, and dictatorial basis.
3. Department heads carry out orders independently and often in accordance with their own whims and desires.
4. As division of labor is only incidental, crude methods may prevail because of lack of expert advice.
5. There is undue reliance upon the skill and personal knowledge of workmen.
6. Foremen may offer resistance to much needed changes.
7. Key men are loaded to the breaking point.
8. The loss of one or two capable men may cripple the entire organization.
9. Difficulty of operation occurs in large or complex enterprises.

The line relationship in modern industry is extremely important, although because of its obvious limitations, as stated previously, there are perhaps few companies, except small shops, that operate entirely by line organization control.

TAYLOR SYSTEM OF FUNCTIONAL FOREMANSHIP.—In the process of his investigations, Frederick W. Taylor, who developed what became known as "scientific management," made an analysis of the duties of a first-class foreman as found in the organization of his day. In his writings he states that such a foreman must:

1. Be a good machinist.
2. Be able to read drawings readily.
3. Plan the work of his department and see that it is properly prepared.
4. See that each man keeps his machine clean and in good order.
5. See that each man turns out work of the proper quality.
6. See that the men work steadily and fast.

7. See that the work flows through the work centers in the proper sequence.
8. In a general way, supervise timekeeping and rate setting.
9. Maintain discipline and adjust wages.

As men with the various aptitudes demanded of such a foreman would be highly valuable, Taylor drew the quite logical conclusion that they would either be advanced to higher positions in their own organization, or induced to join another company, and thus be most difficult

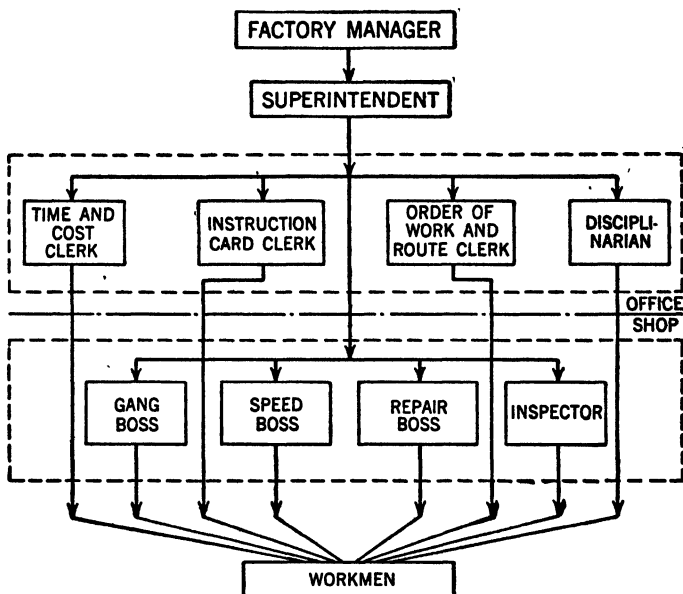



Fig. 4. Taylor Plan of Functional Foremanship

to obtain for the foremanship positions in the shop. However, as many men possessing three, four, or five of these qualities were readily obtainable, he assigned them to specialized duties in harmony with their characteristics and training, such that they would act as functional rather than all-round foremen. He gave this explanation of his idea:

> Functional management consists in so dividing the work of management that each man from the assistant superintendent down shall have as few functions as possible to perform.

The plan really means loading each man to capacity. Taylor discovered, moreover, that the typical foreman of his day was loaded with much clerical duty as well as operating responsibility. He found it necessary to remove the planning activities from the shop, where it was performed at low efficiency and hampered production, into the hands

of men who could specialize in such work. Thus production could be speeded up and costs radically reduced.

The separation of the functions was made as shown in Fig. 4. The time and cost clerk, instruction card clerk, and order-of-work and route clerk attended to the mental and clerical functions of production, while the gang boss, speed boss, repair boss, and inspector looked after the actual production in the shop. A disciplinarian was appointed to look after the disciplinary functions of the whole plant.

The duties of the gang boss were to see that machines were set up for jobs and that work was moved efficiently from machine to machine. The speed boss served as an instructor to the workmen and saw that they maintained the specified rates of production. The repair boss and the inspector performed the duties that their names indicate.

Advantages and Disadvantages of Taylor's Functional Organization.—The marked advantage of this type of organization was that each function was administered by specialists. Expert advice was available to each individual worker and division of labor was carefully planned. In fact, functional organization was highly instructional. The specialists in the various fields served as instructors, with suitable authority.

The marked disadvantage of Taylor's functional plan of organization was that it gave eight foremen or supervisors, in turn, as occasion arose, direct authority or temporary supervision of some form over the individual workmen, whereas it is now clearly recognized that no man can work satisfactorily for, or obey, the instructions of more than one foreman or executive. The plan, moreover, called for so many interrelationships and such integrated coordination that it became cumbersome and topheavy. Its advantages and disadvantages, as analyzed by Bangs, are:

Advantages:

1. Functional organization is based on expert knowledge.
2. Division of labor is planned, not incidental.
3. The highest functional efficiency of each person is maintained.
4. The manual work is separated from the mental—a separation initiated by Mr. Taylor.

Disadvantages:

1. A relative lack of stability is manifest.
2. The coordinating influences needed to insure a smoothly functioning organization may involve heavy overhead expenses.
3. The inability to locate and fix responsibility may seriously affect the discipline and morale of the workers through apparent or actual contradiction of orders.
4. Overlapping authority may give rise to friction between foremen and supervisors.
5. The initiative of supervisors may become stifled. Men may become mere automatons and routine may become very complicated.

Importance of the Functional Idea.—The functional foremanship plan of organization was applied to plants mainly by Taylor, the group of men who were associated with him as consultants, and certain executives who saw the importance of Taylor's work and early adopted his principles and methods. Experience, however, showed the seriousness of its disadvantages as a physical arrangement, and as such it had gradu-

ally disappeared by about 1920. The vastly important fundamental idea of recognizing and separating functions, and having experts and specialists do all the preliminary planning of work in the shop offices, leaving the foremen free to become highly efficient in their four major responsibilities—getting work done according to plan and schedule, setting standards for work, training workers for higher proficiency and gradually increased earnings, and directly handling grievances and all other immediate personnel problems with their workers—has been one of the most significant progressive steps in the entire field of industrial management.

Taylor's developments along the above lines became the basis of the present-day line and staff plan of organization, in which the recognition of functions and the corresponding assignment of specialized advisory and facilitation duties to staff individuals who give their attention solely to such work has tremendously aided and increased the efficiency of line performance of work in the industrial plant.

Some concept of the influence of functional foremanship is gained by examining closely any modern organization chart. Therein, to one familiar with the Taylor plan, it is clearly evident that the functions are all provided for in the following manner:

1. The gang boss is now usually two men, the set-up man, and the move man, trucker, or craneman.
2. The speed boss is the assistant foreman of today.
3. The repair boss has grown into the repair department.
4. The inspector has expanded into the inspection organization.
5. The time and cost clerk has developed into two units—the payroll department and the cost department.
6. The instruction card man has become the time and motion study engineer.
7. The order-of-work and route clerk has developed into two sections —scheduling of work and machine loading, and the methods engineer or individual who plans procedures and prepares operation lists for the parts and assemblies.

Taylor Procedures and Techniques.—While it is true that the Taylor system as a "system" has never been widely adopted, Taylor procedures and techniques have literally changed the make-up of American factories. Among these techniques are:

1. Time study.
2. Functional foremanship.
3. Standardization of tools and machines.
4. The planning department.
5. The "exception principle" in management.
6. The use of slide rules for metal-cutting calculations.
7. Instruction cards for workmen.
8. The task idea in management, accompanied by a large bonus for the successful performance of the task.
9. The "differential piece rate."
10. Mnemonic systems for classification in toolrooms, storerooms and stockrooms.
11. Routing system.
12. Modern systems for timekeeping, cost keeping, and cost accounting.

Of these twelve, only three have not withstood the test of time: functional foremanship, and to some extent the use of slide rules for metal-cutting calculations, and the use of the differential piece rate. All others

have served as a basis for the development of management techniques and procedures and have led to management methods as they are known today.

LINE AND STAFF ORGANIZATION.—In the same way that the Army and Navy have been forced to rely on technical experts and resort to the use of staffs for providing facilities and technical information, so has industry been forced to turn to this plan of facilitation and expert direction. In the line and staff organization, the line serves to maintain discipline and stability; the staff serves to bring in expert information. The staff function is strictly advisory and carries no power or authority to put its knowledge into operation.

The staff officers or services of an organization provide such advice and their duties are as follows:

1. Research into technical, operating, or managerial problems.
2. Determination and recommendation of the various standards of performance.
3. Keeping of records and statistics on the above activities as a measuring stick of performance.
4. Advice and aid in the carrying out of plans and programs.

Separation of Operating Authority and Advisory Service.—Line and staff control makes a clear distinction between doing and thinking—between the actual work of getting things done in the operating and other line departments, and the work of analyzing, testing, researching, investigating, and recording carried on by the staff. It permits specialization by desirable functions, but at the same time maintains the integrity of the principle of undivided responsibility and authority throughout the line organization. A simple diagrammatic illustration of the idea is given in Fig. 5, where the line executives are listed at the left and the staff experts who may assist them with advice are at the right.

Here at the level of president is shown his legal counsel; at the level of works manager, a management consultant, who may be either an outside engineer or a resident industrial engineer; at the level of superintendent, a standards committee; and at the level of foreman, a tool expert. The relation of each one of these staff experts is shown at only one level. However, it is evident that advice from the legal counsel may be given not only to the president but also to any other individual in the line of authority. Similarly, the management consultant may advise not only the works manager but also the superintendent or foreman. Again, the shop standards committee may advise the superintendent and also the foreman, while the tool expert, whose primary responsibility is to advise foreman, may also assist the workmen. That is, Fig. 5, which puts in relationship the line of authority and expert staff, indicates that there are **cross relationships in the line and staff organization** for the purpose of more immediate contact without breaking down the line authority or scattering control.

Advantages and Disadvantages.—The advantages and disadvantages of the line and staff organization, as stated by Bangs, may be summarized as follows:

Advantages:

1. It is based upon planned specialization.
2. It brings expert knowledge to bear upon management and operating problems.

3. It provides more opportunity for advancement for able workers, in that a greater variety of responsible jobs are available.
4. It makes possible the principle of undivided responsibility and authority, and at the same time permits staff specialization.
5. It repays its added costs many times over through the savings resulting from increased efficiency of operations.

Disadvantages:

1. Unless the duties and responsibilities of the staff members are clearly indicated by charts and manuals, there may be considerable confusion throughout the organization as to the functions and positions of staff members with relation to the line supervisors.
2. The staff may be ineffective for lack of authority to carry out its functions or intelligent backing in the application of its recommendations.
3. The inability to see each other's viewpoint may cause difficulty and friction between the line supervisors and staff members.
4. Although expert information and advice is available, it reaches the workers through line officers and thus runs the risk of misunderstanding and misinterpretation.
5. Line supervisors sometimes may resent the activities of staff members, feeling that the prestige and influence of line men suffers from the presence of the specialists.

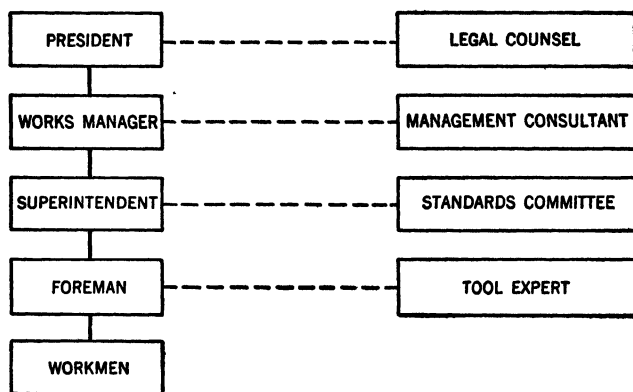



Fig. 5. Illustration of Line and Staff Relationship

COMMITTEE ORGANIZATION.—A third type of organization, the committee form, is supplementary to both line and line and staff organization. In substance the committee is purely an advisory group set up to investigate operating problems or questions which arise from time to time, to make recommendations or formulate procedures, and to turn the results of such deliberations over to the proper executives or supervisors—who often may be members of the committee—for action. Where the committee plan is used to a wide extent, the committees may establish the governing principles of the organization, direct and determine individual executive action, and lay out the major

programs of operation. Thus the activities of the entire organization may be guided in detail by the determinations of the board of directors, executives' meetings, committees of department heads, standing committees to carry on regular assignments in specific fields, and special committees to investigate and develop recommendations on out-of-the-ordinary problems.

Thomas R. Jones, President of American Typefounders, Inc., in his paper on "Theories and Types of Organizations," cites four types of committees:

1. The **committee in actual control,** in which the group assumes power and formulates those decisions for the performance of functions which are usually made by one of the executive officers. Problems are discussed, plans of action are laid out, and orders are issued by the chairman.
2. The **investigational committee,** in which usually each member is assigned to a specific task related to the investigational program, after which the group meets, discusses the problem as a whole, and reports its findings to a line executive, who retains the power to act. Such a committee may be either temporary or permanent, but its function is purely advisory.
3. The **discussion committee,** which is a group formed for the purpose of discussion, such as, for example, one in which representatives of sales, production, finance, and engineering may present their respective viewpoints upon fundamental problems and policies, thus giving the executive officer in charge a wide basis upon which to formulate his decisions. This type of committee acts, of course, only in an advisory capacity.
4. A committee formed for the purpose of **disseminating information, policies, and programs.**

The real functions of a committee are to:

1. Interchange ideas.
2. Secure a meeting of minds.
3. Supply important information to the members or through them to the departments and the organization.
4. Receive and act on reports from committee members or from departments which have been asked for data or information.
5. Assemble facts from many sources and put them together into a combined plan.
6. Assay the results of operations, arrive at conclusions, and formulate reports or suggestions.
7. Make intelligent and expert studies of important factors, activities, or problems.
8. Develop and recommend procedures of operation.
9. Coordinate, or set up time relationships between, the operations of different departments.
10. Correlate or associate together the activities of different departments.
11. Provide for cooperation—or special efforts in performance—between the different departments.
12. Formulate and set up standards of various kinds.
13. Act as a clearing house for matters for which no other channel has been provided.

General Executive Committee.—An excellent example of the need for a committee is shown at the level of authority which includes the sales manager, works manager, controller, chief engineer, and director of industrial relations. These men, with the general manager, represent

the various functions of the executive power. No one of them alone can intelligently decide difficult major questions of policy. But when the five men are assembled as an executive committee, each of the important functions is represented by an executive thoroughly familiar with his own field, the discussions are authoritative, and the decisions have every chance of being sound.

The general manager is logically the chairman of such a committee, and the matters that usually come before the committee pertain to the general policy of operating the factory. Thus, the committee might decide the character and size of the articles to be manufactured. It might approve all manufacturing orders for either stock or special products. It would decide all questions of extraordinary expenditures and would consider all economic problems of the plant.

Equipment Committee.—The equipment committee is made up of men drawn from different ranks, and may consist of a representative of the shop superintendent's office, the foreman of the tool design and tool-making department, the methods engineer, and any other men from the production control, production engineering, or shop departments who may be of service. The chief engineer or his representative may also be included with advantage in this committee. If the plant is large enough to employ an equipment manager, he would be logically the chairman of the committee.

Such a committee would discuss all problems concerning new tools or improvement of existing equipment. When ways and means of reducing the cost of manufacture of any particular line of goods are under discussion, the engineer who is familiar with the line should always sit with the committee. An engineer, a good foreman toolmaker, and a good manufacturing foreman together can often work wonders in reducing costs, which would be beyond the power of any one of them singly. A committee of this kind—when no other specific committees exist—is also very valuable in establishing standards and in advising the executive committee regarding the standardization of products.

Shop Conference Committee.—Under some conditions, a committee composed of a few of the shop foremen, with a representative from the order department, and with the superintendent of manufacturing as chairman, is most effective in solving production problems. Such a committee would discuss all matters pertaining to the operation of the factory and the status of production orders, and the discussion would bring to light any portion of a given production order that was behind schedule, together with the reasons for the delays. The findings of such a committee, in fact, may constitute a progress report of all work in process, and thus put into the hands of the superintendent first-hand information as to what should be done to speed up the work. Committees of this kind, composed of men who are actually in touch with the work, are of great value if they are properly conducted.

Committee Principle.—There is a wide application of the committee principle, not only in the actual work of the factory but also in connection with the personnel side of the organization. A suggestion committee for soliciting and rewarding good suggestions from the workmen regarding factory operation has been found to be a valuable feature in a wide range of plants. Complaint committees for settling differences

between the men and the management often head off more serious troubles. Committees on employee-service work administer benefit and relief activities in many industries.

Committees as Controlling Mechanisms in Large Organizations.—Large enterprises sometimes resort to the committee system for coordinating a wide range of activities. This plan is advisable, particularly if the company operates a number of widely separated plants. The General Motors Corp. is an excellent example of this type of control. Under the committee form of organization action is usually based upon recommendations of advisory committees, appointed by the general manager to study particular problems or phases of operations. These recommendations are evaluated by the operating executives, perhaps in conferences, and are applied, adapted, or rejected according to the judgment of these men who have the power of decision.

From a slightly different point of view, committee management sometimes is carried on by a group of functional executives or department heads rather than by a single general executive. Such an expedient is adopted in cases where the general executive is either limited in his power to act, or hesitates to take responsibility for certain steps without the support of his associates. Such a procedure is more likely to be found in medium-sized concerns than in those that are larger or smaller. In some few cases actual management of the entire business devolves upon the committee. Where such complete committee control is found, it is likely to be a substitute for some capable executive who has left the organization and has not been replaced. Committees that are advisory rather than executive, however, are most effective and survive best.

Advantages and Disadvantages.—The advantages and disadvantages of the use of committees have been summarized by Bangs as follows:

Advantages:

1. Under a strong executive chairman, a committee may quickly marshal many valuable points of view, since "two heads are better than one."
2. In conducting investigations, the several phases of the various questions may be quickly assigned to responsible members with a reasonable assurance of speedy action if a time schedule and proper follow-up are instituted.
3. Decisions arrived at are impersonal, leaving the chairman free from the personal criticism so often leveled at a managing executive.
4. There is a stimulus toward cooperative action.
5. The members of the committee know better what is going on in the plant so that they can spread the information and team up with other individuals or departments.

Disadvantages:

1. Committees may be too large for constructive action. The number of members should seldom exceed three.
2. Committees are expensive in time and usually have to be prodded to prevent delays.
3. Important executives may be called so frequently from their work for meetings that the operations of the enterprise slow down.
4. The members of the committee often are unfamiliar with important details of questions at issue and therefore may make wrong or ineffective decisions.

5. Action may often be superficial because of lack of time or the disinterestedness of committee members.
6. Committees weaken individual responsibility and make for compromise instead of clear-cut decisions.
7. The decisions often are made to conform with what it is assumed some executive wants, or to enable the members to avoid direct responsibility for any bad results.
8. Aggressive and outspoken members may dominate committee meetings and unduly influence the action, often adversely.

CRITICISM OF COMMITTEES.—In modern industry a great deal of time—probably too much—is spent in committee meetings or conferences. No less an authority than Henry Ford has said, "Conferences will kill any man."

Urwick is severely critical of committee operation. He states that better results by far can be secured in most cases when an executive himself obtains the necessary information and advice and acts on questions within his field of authority. Conferences among executives are necessary to obtain information and find out how the problem at stake affects other departments, but then the executive should take action. Most frequently, matters are referred to committees when individual executives wish to dodge responsibility or avoid friction. The committee decision is a make-shift or compromise worked out by persons many of whom have only a remote idea of the matter at stake and very little ability to give even an opinion of value on the subject. Yet such persons are often most insistent in expressing themselves. Finally, the committee may state its conclusions in a manner to avoid committing itself to anything which may be held against it later. In short, much committee activity, from start to finish, may be merely "passing the buck."

JOINT MANAGEMENT-LABOR COMMITTEES.—In connection with efforts to increase production and settle matters of mutual interest, joint management-labor committees were introduced into many plants in the past few years. The plan followed was to set up a committee composed of representatives of both groups, whose work would be to find out ways in which productive energies could be more efficiently applied and ways of eliminating wastes and losses could be developed. Workers were known to have ideas which could be turned to good account but even in plants with suggestion systems already in effect, many such ideas, it was found, were not brought to the attention of the management.

Method of Organization and Operation.—Several hundred plants quickly took up the committee plan when it was first launched. An equal number of management and labor representatives were appointed in each case, say from two to six of each, to the joint committee. Where there were labor unions, it was customary to work with them in setting up the labor representation. Sometimes departmental committees were organized. The central committee then often set up subcommittees to go out after ideas and make investigations to see what improvements might be brought about. Such subcommittees, for example, might handle publicity, suggestion systems, production efficiency, methods improvement, subcontractor difficulties, materials conservation, etc. Reports of these subcommittees were discussed and the recommendations approved, modified, or rejected by the main committee. The committee did not

carry on collective bargaining, nor act on questions of wages, hours, and other matters which were negotiated either through the unions or other channels. No authority covering plant activities was taken over by labor. The plan was merely to go into matters which would improve production or otherwise improve operations. Usually a management member was assigned to take over the work of seeing that the decisions on such matters were communicated to the proper person so that the improvements would be brought about. In many plants meetings were held at stated intervals during working hours, but in some cases they were held outside of hours and without pay.

Results Secured.—As was natural, the use of suggestions, and often the setting up of a suggestion system, was a vital part of the program. While some ideas brought out were to a certain extent fundamental, most of the suggestions were on everyday operating problems and individually small in effect, but the total improvements and time saving were highly significant. Production increases averaging 25% were indicated as possible under the plan. Some plants found as high as 70% of the suggestions usable. In addition to these benefits, the opportunity for coöperation in an effort where there were no conflicting interests was important and a forerunner to further joint efforts in lines where there was a common cause.

The plan has been somewhat misconstrued throughout industry as to its ultimate implications. It does not replace dealings between management and workers on questions which are subject to collective bargaining. It does not confer upon workers any management authority. Where regular channels existed for management-worker contacts and dealings, and for the use of suggestion systems with financial awards, job methods training to teach employees how to develop suggestions, and similar plans, the committee method merely coordinated and stimulated such activities, brought the results together, and moved to have the necessary action taken promptly to bring about improvements that might otherwise have been indefinitely postponed. In cases where suggestion systems were already in operation, plants sometimes put the new effort on a separate basis, and in certain instances gave certificates as well as cash awards.

Occasionally labor committeemen were able to call attention to some definite management oversights and neglects. But there was no assignment of authority which took over management's prerogatives so that the plants became actual cooperatives with labor exercising an equal voice in all matters concerning the business. In fact, the results proved that even labor did not feel itself qualified to assume directional responsibility and, apart from its ambitious leaders and organizers, had no desire to assume management's function with all of the problems, difficulties, and dangers involved.

Use of the Plan.—Although the field of action has been thus determined and the good results secured prove that the joint committee plan is successful, it is not the final solution to all management-labor problems.

It does not mean the supplanting of national by company unions. It bears no resemblance to the plan proposed by Reuther for the automotive industry, which calls practically for the management and control of the activities and facilities of the whole industry. Neither does it approach the plan urged by Murray, which comprehends a central

control board for each major industry, in which management and labor, on an equal basis, would set the policies, control the construction and use of all manufacturing facilities, allocate contracts and materials, determine the general program of production and all the factors in which labor is in any way involved, and thus practically direct the industry. Finally, it is not the plan of organization suggested by Lewis, which conceives of separate but affiliated industry unions whose representatives would deal on an equal basis with representatives of the management's trade association in the industry to set up and direct the entire conduct of the industry.

The joint management-labor committee plan has the following advantages:

1. It serves as a medium for the stimulation of ideas and giving proper recognition and rewards for such ideas. In other words, it gives permanence to the suggestion system.
2. A forum is provided for the exchange and the weighing and recommendation of helpful suggestions by means of which mutual benefits are secured.
3. The basis is set up for discussing matters of common interest in operations and conditions so that management and labor see each other's problems and help in their solution without either side stepping into the province of the other—management aiding in offering opportunities for recognition and advancement to workers, but avoiding anything to hamper labor progress, and labor contributing means for bettering activities without assuming management authority.
4. A means for better understanding with unions.

STAFF PLAN OF COORDINATION.—Apart from the line and staff provisions for extending advisory aid to operating executives by means of staff specialists assigned to specific fields of activity which concern several of the individual divisions or departments of the enterprise, there is further need of coordination throughout an industrial organization. In large organizations especially, the divisions or departments are often so extensive as to demand the concentrated attention of the division heads to the exclusion of their cooperative participation in each other's activities. There are fewer men, moreover, who have such a general grasp of the business that they can line up their individual activities to the best advantage with the activities of other divisions. It has become necessary, therefore, to provide a medium through which these diversified lines of work may be coordinated so that the entire organization may team up, with each unit handling its tasks along lines and according to schedules which produce the desired final results effectively and at the right time. In a study which the Niles made of this subject, the fact was brought out that suggestions should be more widely sought from both formal and informal individuals appointed as coordinators, regardless of their rank or title, and that these suggestions should be widely used in the operations of the company. The three important aids to such coordination are:

1. An understanding of the nature and divisions of functions and authority.
2. A determination of the number and types of persons who can be grouped under the same executive.
3. Development of staff assistants to aid line executives in work not delegated to regular line assistants.

Staff Assistants.—Further, the division heads need additional aid within their own areas of operation, and the appointment of staff assistants to the division heads may provide the required help. The practice of having assistant superintendents, assistant chief inspectors, etc., is well recognized but these men have line authority under their executive directors. The staff assistant, however, would not manage any of the work, and his rank would be junior to his chief's leading line assistants. He would serve as contact man between his chief and the other members of the department. In this capacity he would translate the decisions of his superior into a working program and correlate the work of the various sections of the division. He would fulfill both planning and personnel functions. The only line authority he would have, however, would be that delegated to him in carrying out his chief's direct orders. Administrative officers would similarly have assistants to aid them in discharging administrative functions.

Duties of Staff Assistants.—The Niles in their writings outline the duties of staff assistants as follows:

1. Prepare information and recommendations:
   a. Compile appropriate information.
   b. Make recommendations for action.
   c. Investigate proposals from other sources.
   d. Check on results obtained.
2. Aid in formulating instructions and making decisions:
   a. Give out orders for the chief.
   b. Make decisions in certain cases where policies and procedures are established.
3. Assist in contact work:
   a. Interview individuals for the chief.
   b. Save the chief's time.
   c. Arrange interviews between individuals and the chief.
   d. Make reports on activities.
   e. Settle minor complaints.
   f. Disseminate information.
   g. Coordinate the division's activities and correlate its work with that of other divisions.

Among the **things which a staff assistant should not do** are to:

1. Take over line duties.
2. Give advice as a specialist.
3. Merely make investigations without recommendations.
4. Only make suggestions when instead he should take some action.
5. Assume authority over subordinate line men.
6. Be guided by his own personal opinions.
7. Exceed his authority.
8. Talk too much or reveal matters which should be kept confidential.

By serving as staff assistants men are trained for promotion to executive duties and are tried out as candidates for such advancement. If they do not make out well in the staff assignment, they will be limited to subordinate positions. Those who demonstrate capability may develop into successful management prospects.

MULTIPLE MANAGEMENT.—In any company with more than approximately 100 employees, the problem arises of maintaining close relationships between management and employee. Important questions

are: How can employees be given a feeling of participating in company? How can management keep employees informed? How can management be extended down to the intermediate levels of authority as the company grows?

An executive plan, now tested through depression, prosperity, and war, was put into operation at McCormick & Company by its president, Charles P. McCormick, in 1932 and has been in successful operation ever since. The plan has been described and has had wide publicity in Mr. McCormick's book "Multiple Management," distributed in both English and Spanish language editions. Multiple management has been adopted with variations for changing circumstances by approximately 500 business firms of all types in the United States, England, and Australia.

The Four Boards.—Under this plan, in the McCormick Company, management has extended to approximately 50 executive and supervisory men in the company through a system of four boards.

The Senior Board is comparable to the board of directors in any company, is elected by the stockholders, sets up and controls company policy, and acts through its members as a clearing house for final decision on all recommendations from the other boards.

The Junior Board is a group of approximately 15 younger executives representing the office and executive group. It meets regularly once a week to consider any matters dealing with company affairs it cares to investigate. Its recommendations must be unanimous, and become final only upon approval of the senior board member concerned with the suggestion.

The Factory Board represents the factory, warehouse, and shipping department unit of the business. Problems concerning production schedules, stock control and shipping, machinery and maintenance are discussed at regular weekly meetings. Recommendations must be unanimous and approved by the senior board member concerned.

The Sales Board is composed of 10 active and 5 associate members chosen from the outside sales force actually calling on the trade, plus 5 inside sales executives. This board, because of the distance to be traveled by its members, meets only twice a year usually for a week at a time. The committees secure cross-section opinion of the sales force between meetings, and resolutions passed unanimously for senior board approval at sales board meetings represent the opinion of the salesmen on merchandising, advertising, sales training, and similar subjects.

Operation of the Boards.—Provision is made to give eligible men in the company on the boards an opportunity to be elected through an arrangement that at each semi-annual election of the junior, factory, and sales boards three members must be dropped from each board and replaced with three new men. Over a 10-year period 87 men served at one time or another on the factory board and 65 on the junior board. Elections are handled by a merit-rating system whereby each board member rates on a rating chart the abilities of every other member. The three members who are lowest on the semi-annual rating chart on each board are dropped off and replaced.

The employees do not elect the members of the board, because the tendency would be to select on popularity rather than on merit. However, the employees have a feeling of participation in that men they

know and work with in their departments every day are actually directors in management. For example, a girl on a factory machine feels much freer to present her ideas or problems or suggestions to the young man who comes around as a mechanic on that machine, who is a member of the factory board, whereas she would never have a similar opportunity to talk things over with a top executive on the ordinary board of directors of the company. Thus management is actually extended down to every employee through a representation system.

Benefits to Employees and Company.—The new spirit and attitude on the part of employees resulted in 12% increase in production within the first 2 years after the plan went into effect. The factory board has put in such benefits as rest periods each morning and each afternoon, music for the girls in the factory, and guarantee of a full year's work to provide security. The junior board has inaugurated four parties annually, and improved the vacation schedule and retirement pension plan. Employee turnover in peacetime was reduced to approximately 3% and absenteeism in wartime averaged approximately 5% as compared to 12% common in the area. Company profits have increased each year, dividends have been paid regularly to stockholders, and employees have been paid regular profit-sharing bonuses.

Multiple management in the company has brought management and employee closer together, as trained leadership, to the extent that 9 members of the early junior boards are now members of the senior board, has discovered talent by giving new employees a chance to be sponsored in management by junior or factory board members, and has produced valuable ideas. The junior board alone recorded in its minutes 2,709 unanimous recommendations on various matters of company policy and operations in a 5-year period.

Factors in Planning an Organization

ALLOTMENT OF DUTIES IN AN ORGANIZATION.—Duties or activities in an industrial organization are allotted to individuals by several different methods, of which the following are the more important:

1. By persons—an executive or supervisor is given authority over, and made responsible for, certain subordinates.
2. Within physical boundaries—an executive or supervisor is given supervision over a room, a department, or a production center.
3. By production—an executive or supervisor is given supervision over the manufacture of a particular item of product, or a certain line of product.
4. By process—an executive or supervisor is given supervision over a particular manufacturing process, or over a series of such processes.
5. By equipment—an executive is given supervision over a particular group of machines or class of equipment.

The above **allotments are in the nature of vertical subdivisions** where each executive's or supervisor's authority is exercised within his determined sphere of control but subject to higher line authority and to functional or expert staff advice.

THE LADDER OR BRIDGE OF FAYOL.—However, in addition to vertical, there are **horizontal relations** which have received but little study and managerial attention. In this connection there is a nearly

unexplored field, where the vertical lines of authority cross and conflict with the horizontal lines of relations. This situation is made plain from a consideration of Fig. 6.

This diagram represents two lines of authority apexing in the president and in each case following through a works manager, superintendent, department head, supervisor, and foreman to the workman. It is evident that, to perform duties assigned to each line—assuming that they are in same industrial organization—there must be some contact, communication, and relationship between individuals at each level of authority in the two converging lines. Such relations may be concerned with: (1) jurisdiction, that is, a determination of which line is to do certain work; (2) coordination of policies and operation methods needful to secure uniform operating results; (3) review and criticism of

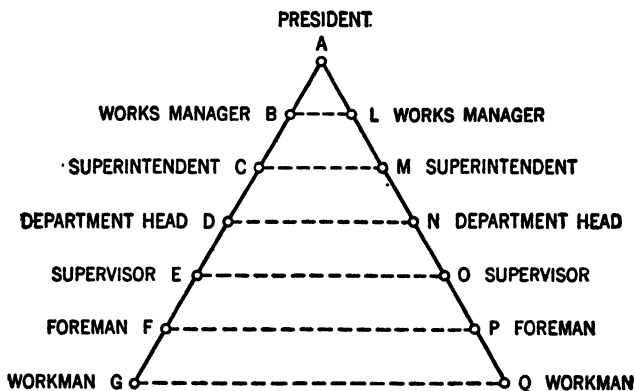



Fig. 6. Cross Contacts or Relationships Illustrated by the "Ladder" or "Bridge" of Fayol

work, which may occur where work is transferred from one line of authority to another in order to complete succeeding operations; and (4) division of overlapping duties. The points where vertical authority and cross relations meet are illustrated by the small circles in the diagram. In practice these relations are real and continuing, and give rise to **points of possible friction and conflict.**

Essentials for Maintaining Intersecting Relationships.—Fayol, whose "requirements for command" have been previously mentioned, set up the essentials for establishing and maintaining these intersecting relationships on a frictionless and properly managed basis. Essentially his solution is a process of self-adjustment. He pointed out that executives at any level in line of authority may contact one another, reach decisions, and initiate action, provided these requirements are satisfied:

1. Contact or relationship should be initiated only with the consent of the immediate line superiors.
2. Before any action is taken, it must be approved by the immediate line superiors.

Fayol's statement of his method (Industrial and General Administration) is:

The need for a **hierarchic channel** arises both from the need for safe transmission of information and orders and from unity of command, but it is not always the quickest channel, and in very big enterprises, the State in particular, it is sometimes disastrously long. As, however, there are many operations whose success depends on rapid execution, we must find a means of reconciling respect for the hierarchic channel with the need for quick action. This can be done in the following way:

Let us suppose that it is necessary to put function F in communication with function P, in an undertaking whose hierarchy is represented by the double ladder G-A-Q (see Fig. 6). In order to follow the hierarchic channel, we should have to climb the ladder from F to A and then go down from A to P, stopping at each rung, and then repeat this journey in the opposite direction in order to get back to our starting point.

It is clearly much simpler and quicker to go straight from F to P by using the "bridge" F-P, and this is what is most frequently done. The hierarchic principle will be safeguarded if E and O have authorized their respective subordinates F and P to enter into direct relations, and the situation finally will be perfectly in order if F and P immediately tell their respective chiefs what they have agreed to do. So long as F and P remain in agreement and their actions are approved by their immediate superiors, direct relations can be continued, but as soon as either of these conditions ceases to exist, direct relations must stop and the hierarchic channel must be resumed.

Use of the "bridge" is simple, swift, and sure; it allows the two employees F and P, in one meeting of a few hours, to deal with a question which by the hierarchic channel would go through 20 transmissions, inconvenience many people, entail an enormous amount of writing, and waste weeks or months in arriving at a solution, which would probably not be so good as the one obtained by putting F in direct contact with P.

SPAN OF CONTROL.—By the term "span of control" is meant the number of subordinates who can be successfully directed by a supervisor or superior. In the direction and control of industrial enterprise it has long been apparent that delay, friction, and confusion can be traced to the fact that too many subordinates are assigned to one superior.

The theory of Graicunas states that in an organization there are **three kinds of relationship**: direct single, direct group, and cross.

In almost every instance a supervisor measures his responsibility by the number of direct single relationships between himself and his subordinates. He thinks of a group of 12 employees as requiring twice the work of supervision as a group of 6. However, there are direct group and cross relationships to be considered as well as the simple direct. To illustrate:

Designate the supervisor as A, and assume that he has only two subordinates, B and C. It is evident that A can deal individually with B and with C, or he can deal with them as a pair. The behavior of B in the presence of C will differ from his behavior if he alone is with his superior, A. Furthermore, the attitude of B toward C, and C toward B, constitute cross relationships which A must keep in mind in arranging the work of B and C. It is evident that B and C might have widely

different racial, political, or trade union affiliations, which would have no influence upon either as a good workman working alone, but which might prevent them from working together harmoniously. Then again, some individuals, the so-called "lone wolf type," cannot work well with others, no matter who they may be.

The relations among a supervisor, A, and two subordinates, B and C, are:

Kind of Relationships	Minimum Basis	Maximum Basis
Direct single relationships:		
A to B, and A to C	2	2
Cross relationships:		
B and C	1	
B to C, and C to B		2
Direct group relationships:		
A to B and C	1	
A to B with C, and A to C with B		2
	4	6

It is evident, then, that in this simplest unit or organization there are from 4, on a minimum basis, to 6 relations, on a maximum basis, demanding A's attention, instead of only two. It is evident, further, that direct single relationships increase in the same proportion as the number of subordinates assigned to a supervisor. The number of direct group and cross relationships, however, increases more rapidly than the increase in number of subordinates as more are assigned to a supervisor. On a minimum basis these relationships are counted once for each combination of subordinates. The direct group relationships can be conveniently shown by the following analysis:

Number of Subordinates Reporting to One Supervisor A	Number of Direct Group Relationships
Two Subordinates B, C:	
Direct group relationships ABC	1
Three subordinates B, C, D:	
Direct group relationships ABC, ABD, ACD, ABCD	4
Four subordinates B, C, D, E:	
Direct group relationships ABC, ABD, ABE, ACD, ACE, ADE, ABCD, ABCE, ABDE, ACDE, ABDE	11
Five subordinates B, C, D, E, F:	
Direct group relationships ABC, ABD, ABE, ABF, ACD, ACE, ACF, ADE, ADF, AEF, ABCD, ABCE, ABCF, ABDE, ABDF, ABEF, ACDE, ACDF, ACEF, ABCDE, ABCDF, ABCEF, ABDEF, ACDEF, ABCDEF	26

The process of extending the diagram beyond this point is self-evident. On a minimum basis—used in the diagram above—the number of direct group relationships for 6 subordinates is 57; for 7 subordinates, 120; and so on.

On a minimum basis the increase in total number of relationships between a supervisor and his subordinates, as the number of subordinates

increases, can be determined mathematically from the following formulas:

Let N = Number of subordinates
A = Number of direct single relationships
B = Number of cross relationships
C = Number of direct group relationships
$F = A + B + C$

Then $A = N$

$$B = \frac{N}{2}(N - 1)$$

$$C = (2)^N - (N + 1)$$

Solving the above formulas for the number of subordinates from 1 to 10 yields the tabulation shown in Fig. 7.

Graicunas assumes that it is possible for one supervisor to give adequate attention to a **maximum of only 12 cross and 28 direct group relationships,** from which comes the conclusion that, in cases other than the simplest of routine work, the number of cross and direct group relationships governs the number of subordinates to place under a supervisor. A strict application of this conclusion indicates that the span of control should be restricted to a maximum of 5 subordinates.

This theoretical conclusion, that number of subordinates reporting to a superior should be few, has ample support from practice. The smallest organizational unit in an army is the squad, made up of a corporal, or supervisor, and 7 privates, or subordinates. Many factories limit the number of employees under a supervisor to some 8 or 10. Practically, a supervisor can probably direct 10 to 12 workers before there is a considerable falling off in his directive efficiency.

Turning to higher levels in the line of authority, Swope has said that 4 or 5 subordinates reporting to a chief executive are a sufficient number for good organization. However, the nature of relationship between superior and subordinate at any level in the line of authority should govern the extent of responsibilities of the superior. It is true here, as in many other relationships in industry, that no hard and fast rule can be laid down.

Davis (The Influence of the Unit of Supervision and the Span of Executive Control on the Economy of Line Organization Structure) has made a study of the span of control, assuming at successive levels that each executive has 5 subexecutives under him, and that, at the workers' level, there are 20 employees reporting to each foreman. The analysis has been graphed for present purposes in Fig. 8 and the Davis tabulation, rearranged, is given in Fig. 9.

Factor in Formulas	Number of Subordinates									
	1	2	3	4	5	6	7	8	9	10
Values of A	1	2	3	4	5	6	7	8	9	10
Values of B	0	1	3	6	10	15	21	28	36	45
Values of C	0	1	4	11	26	57	120	247	502	1013
Values of F	1	4	10	21	41	78	148	283	547	1068

FIG. 7. Increase in Interrelationships as Number of Subordinates Increases Under the Span of Control

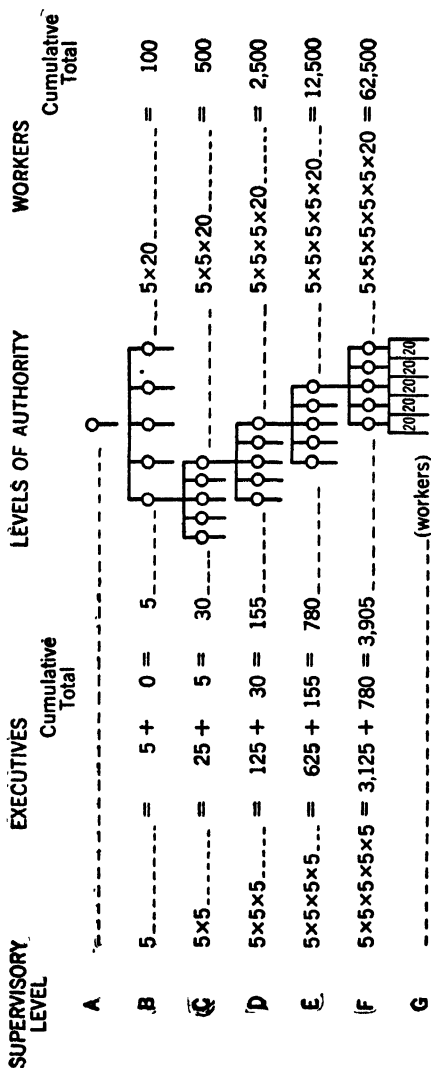



Fig. 8. Graphical Analysis of the Span of Control

Constructed by assuming the several successive executive levels indicated below chief executive A (5 subordinates for each subexecutive, in turn), and calculating the number of subexecutives, and finally the number of workers (20 per foreman), in turn for the successive assumptions (see also Fig. 9).

Level	Service Levels Required*	Span of Executive Control	The Unit of Supervision	Number of Operating Executives	Number of Primary Workers Who Can Be Supervised
A	....	....	....	....	....
B	1	5	20	5	100
C	2	5	20	30	500
D	3	5	20	155	2,500
E	4	5	20	780	12,500
F	5	5	20	3,905	62,500

* Between workers and the head of the line.

FIG. 9. Geometric Increase in Number of Primary Operative Employees and Number of Operative Executives with Increasing Size of Line Organization (See also Fig. 8)

Davis explains his terms in this way:

A major service level may be defined as one that represents a major change in the kind or type of employee service that is required. It may be broken down, of course, into a number of minor service levels. While minor service levels are important in such problems as wage and salary classification, they are not important in this problem. When the term "service level" is used, it refers to major service levels only. A major service level is an important organizational factor, affecting the number of high-salaried executives who will be required and the complexity of organizational relationships. In general, the larger the number of major service levels required, the greater the number of staff organization units that must be set up, and the greater the complexity of the relationships between them and with the line organization. The number of major service levels required is an important factor in wage and salary classification and standardization, development of promotion methods, and in the solution of other managerial problems, as well as in the analysis and planning of organization structure.

EXECUTIVE LEVELS.—An important factor in organization is to study the set-up from the standpoint of the respective levels of executive rank. Including the president, it is desirable to have no more than 6 levels, and less if possible, down to the workers themselves. Reference to Fig. 9 indicates that even the largest plants can function successfully with that maximum number of levels. The Army and Navy, with their millions of men and the myriads of problems involved in time of war, operate with remarkable effectiveness under about 13 levels.

The usual organization chart, to remain condensed in area, must picture the various positions according to the descent of authority down the line. Some divisions and departments have few levels between the top executive in charge, who reports to the president, and the supervisors who have the final titles just above the rank of worker. Other departments have several such levels. Hence it is not customary to try to show across the chart, horizontally, the respective levels or ranks of positions among the different departments. Merely the descent of authority for each department, independently, is shown. Neither is it easily possible to picture the evaluation of the various positions horizontally across the chart. The rates of salary vary between departments, irrespective of relative rank or level, some kinds of work requiring much higher remuneration because of their nature, and seniority of service—accompanied by demonstrated ability—usually bringing properly with

it a larger salary than is paid to others of approximately equal rank but with shorter periods of experience. Likewise, the number of persons over whom the executive or supervisor has charge may be a factor in settling his relative rank. Even the organization manual in which the duties and responsibilities of each position are written up cannot indicate clearly the relative levels or ranks of jobs horizontally throughout the organization.

DETERMINING THE LEVELS.—In spite of the difficulties of determining levels and ranks, it has been done in the armed forces and should be done in industry. This step involves more than a determination of respective duties and responsibilities and covers the general sphere of influence which the individual governs, and the relative rating of his position as compared with other jobs throughout the entire company. If a good job evaluation plan is in effect in the organization, the basis for rating positions on their relative levels is well established. In fact, this is one of the elements in job evaluation. Fine shades of distinction in rank are unnecessary as well as impossible.

Probably the best approach to the problem—with or without job evaluation in effect—is to set up three or four general ranges of rank or levels under which the respective positions will be grouped. The Niles have recognized the importance of this method in their book on Middle Management, which discusses the subject mainly in the field of office organization. It is of equal importance from the plant viewpoint.

THE FIVE IMPORTANT LEVELS.—There are five important levels into which members of the executive and supervisory employees may be classed. These levels are:

1. Top executives
2. Senior executives
3. Intermediate executives (often divided into two, or even three, ranks according to the nature and size of company)
4. Junior executives
5. Supervisors and foremen

Top Executives.—In the ranks of top executives are the officers of the company. Typical titles are:

1. President
2. Vice-President in Charge of Engineering
3. Vice-President in Charge of Manufacturing
4. Vice-President in Charge of Sales
5. Vice-President in Charge of Industrial Relations
6. Secretary
7. Treasurer
8. General Manager

These men discharge major responsibilities and exercise a wide range of authority. They are directly concerned with the application of the basic policies of the company and the direction of its respective major lines of activity. Likewise they establish the central coordination between the principal activities and should have delegated to them practically full authority—subject to company policies and the responsibilities of, and relationships with, other activities—to carry on their work according to plans which they themselves largely develop.

Since there is no definite standardization of titles of positions among industrial organizations, the titles employed here are descriptive and

indicative rather than specific and exact. Thus, where there is a general manager, he presumably would exercise immediate direction over the activities of engineering, manufacturing, sales, and accounting, and perhaps over industrial relations. There might be a vice-president, but his position, and those of treasurer and secretary, might cover corporate duties of a special nature, rather than operating responsibilities, although the vice-president might also be the general manager.

Senior Executives.—In the class of senior executives may be men such as the chief engineer, factory manager, sales manager, purchasing agent, controller, personnel director, and two or three others with related titles. While these men do not have the official rank entitling them to the designation of top executives, they carry heavy responsibilities and exercise full authority in their respective areas of action. They are rated as executive heads of the divisions or departments of which they have charge. Their tasks are to break down the company's basic policies, particularly the ones governing their lines of work, into directive regulations and to develop the fundamental procedures for their respective divisions or departments.

Intermediate Executives.—In moderate-sized and large companies the senior executives have immediate assistants who are qualified in some cases to take over the work of the division or department in the absence of their chiefs, or to aid him by performing certain of his duties or handling special assignments. Such men usually are chosen to succeed their chiefs if the latter leave or are promoted to higher responsibilities. Reporting to the chief engineer, for example, would be an assistant chief engineer or perhaps an executive engineer; to the factory manager such men as a manufacturing manager, production control superintendent or manager, chief inspector, works engineer, and perhaps others with corresponding duties. Under the sales manager would be an assistant sales manager; under the purchasing agent, an assistant purchasing agent; under the controller, a chief accountant, cost accountant, statistician or budget director, and office manager; and under the personnel director, an employment manager, training director, employee-service manager, a specialist in industrial relations and bargaining with workers, and perhaps a safety director.

To these first-rank intermediate executives are often assigned particular areas of work in the division or department. They become, in effect, specialists in such lines and usually assume practically full direction of the activities which they supervise. They are responsible for the direct application of the immediate policies of the company, the development of specific procedures for the performance of the work, and direct supervision over assistants carrying more detailed assignments.

In the second rank of intermediate executives are classed important subexecutives who work under the direction of those in the first rank. The assistant chief engineer would have reporting to him perhaps a chief draftsman, in some cases project engineers, and engineering specialists who are chiefs of other sections, notably chief of structures and chief of weights in the aircraft industry. The manufacturing manager may have superintendents who head departments. The planning superintendent would have a methods engineer, a chief time study engineer, a chief of planning, and related heads of units under his jurisdiction.

Under the assistant sales manager might be an advertising manager, a field sales manager, etc. Under the assistant purchasing agent would be buyers and others in responsible positions connected with purchasing; and under the employment manager, a director of employee tests, and a chief of shop training, and heads of other personnel sections. The chief accountant would have assistants specializing in specific phases of accounting, such as accounts receivable and accounts payable.

In all cases these subexecutives would be in charge of detailed sections of work which, in large companies, would be still further subdivided into units to be handled by junior executives. Certain decisions are required of the intermediate executives, and they are responsible for the development and improvement of various techniques and procedures. They would have direct control over their assistants and would be held responsible for the proper performance of the work.

Junior Executives.—The level of junior executives includes those who have begun their progress through the organization through experience or training which qualifies them to head a smaller unit of the enterprise and direct the work of a few assistants or supervisors. Under the chief draftsman may be a chief checker who may direct the work of drawing inspection and checking; under the superintendents would be assistant superintendents; under chief of planning there may be a schedule man who lays out the program for factory work. The field sales manager often has branch managers. Buyers sometimes have assistant buyers. The chief of shop training may have a head instructor in machine-tool work, and a head safety-training instructor.

Junior executives in some cases would direct the work of subexecutives in the ranks of supervisors or foremen, especially in the factory departments. Assistant superintendents, for example, may have general shop foremen covering particular units of the plant engaged in distinctive kinds of work such as foundry, forge-shop, machine-shop, etc. In other cases the junior executive may head a unit of workers, sometimes operating under group leaders, who are performing some definite kind of work, especially in the office, engineering department, or laboratory. His responsibilities include the making of decisions, giving of advice, and the development of procedures. He is therefore doing an executive class of work rather than conducting an operation. Consequently he should be rated in the executive category rather than as a supervisor or foreman.

The junior rank involves activities in many of which the individual is on his own, but in which he has the ready aid of some chief close enough to his work to guide him in his decisions and procedures. At the junior level, therefore, the executive applies on his own responsibility many of the things he learned as a worker and supervisor, but at the same time he is on the "proving ground," being tested in his ability to use what he knows, to train others, and to be a leader in getting work done and in commanding not only the obedience but also the respect, high regard, and loyalty of his subordinates. No man who demonstrates mere "drive" for accomplishment, but fails to continue his own training and lacks the power of building his assistants into a loyal and efficient team should be promoted into the intermediate or higher ranks.

Supervisors and Foremen.—In immediate charge of employees are supervisors and foremen. Many companies distinguish between these

two terms, implying by the title of "supervisor" that such men have semi-advisory or assisting duties included in their range of activity. The term "foreman" is then used to indicate that the holder of this title actually directs employees in their work. The designation "foreman" is likewise used with different implications in different plants. Sometimes a foreman heads only a small group of workers. In other cases an individual with this title may head a department of one or two hundred, or more, workers, in which case he would be aided by assistant foremen, under whom subforemen or group or squad leaders would work. Each person immediately in charge of the performance of the work, therefore, would have perhaps from 5 to 20 workers under him.

Persons in supervisory or foreman ranks are responsible mainly for four important functions:

1. Getting work done in the time, and of the quality, set by careful and coordinated planning.
2. Setting standards for the work in conjunction with the special units (methods, time study, inspection, etc.) particularly concerned with such problems.
3. Training workers to perform their tasks better so that spoilage will be cut down, quality maintained, and output increased, thus enabling employees to add to their earnings.
4. Handling grievances in the department, thus eliminating causes of dissatisfaction as soon as they arise and thereby maintaining good labor relations.

INTERCOMMUNICATION BETWEEN THE VARIOUS LEVELS.—A good organization functions with freedom of communication among its executives regardless of their respective positions. In well-run companies a junior executive may ask for advice or aid from some senior executive in another department by direct approach, when his problem concerns, or is affected by, some element under the senior's control. Senior executives may likewise secure the aid of junior executives. There is no violation of line control in such contacts, and they improve the efficiency and speed with which work is done.

QUALIFICATIONS OF A TOP EXECUTIVE.—Considerable discussion has been devoted to the question as to what are the important qualifications of a competent top executive: Coes has suggested the following (Mech. Eng., vol. 65):

1. Character, that is, honesty, integrity, loyalty, truthfulness, fairness, tolerance, firmness.
2. Orderliness in mind and in action.
3. Poise and control of temper, not desk pounding.
4. Respect for time, its value, and its use.
5. Ability to assume responsibility.
6. Ability to cooperate.
7. Ability to take and to give constructive criticism.
8. Ability to compromise when necessary.
9. A sense of humor.
10. Broadmindedness.
11. Action without procrastination.
12. Wisdom to understand that it is no sign of weakness to seek help from competent sources.

13. Clarity of thought—the ability to reason from the facts, draw sound conclusions, and then act.
14. Good judgment, acting intuitively at times without the aid of logical reasoning. In fact, with only the facts at hand at the time the decision must be made, logical reasoning from the facts will frequently produce a conclusion at direct variance with what judgment dictates.

Another list of significant qualifications (Johnson, Business and the Man, Alexander Hamilton Inst.) includes additional factors:

1. Creative power
2. Initiative
3. Energy
4. Courage
5. High ideals
6. Honor and integrity
7. Independence
8. Responsibility
9. Executive ability

QUALIFICATIONS OF OTHER EXECUTIVES.—It is important that executives from the senior down to the supervisory and foremanship levels be trained so that they may acquire at least some degree of the characteristics listed above for the top executive. In addition, there is need for emphasis on specific characteristics or qualifications of a more detailed nature in each case.

For senior and intermediate executives, the factors of initiative, integrity, dependability, and coordinative ability are particularly important. Such characteristics indicate the ability to forward and carry through the ideas and plans of top executives.

In the case of junior executives, the list may include qualities such as:

1. Adequate training and experience
2. Ability to contribute new ideas
3. Willingness to learn
4. Adaptability
5. Capacity for detail
6. Teamwork
7. Loyalty
8. Ability to follow instructions
9. Leadership

A still more specific list may be given for the qualifications of supervisors and foremen concerning their four fields of activity stated in a previous paragraph (Johnson, Business and the Man):

1. For directing or handling work
   a. Mechanical ability
   b. Versatility and ingenuity
   c. Knowledge of equipment
   d. Familiarity with modern practices
   e. Ability to correlate activities
   f. A cooperative spirit
   g. Understanding of costs
   h. Safety consciousness
2. For setting standards
   a. Engineering sense
   b. Knowledge of job requirements
   c. Sense of relativity
3. For training
   a. Teaching ability
   b. Knowledge of crafts or subjects taught
   c. Patience
   d. Perseverance
   e. Ability to develop men
4. For handling human relations
   a. Sympathetic understanding of human nature
   b. Trustworthiness
   c. Fairness
   d. Tact
   e. Discernment
   f. Self-control
   g. Freedom from prejudice
   h. Ability to translate company policies into practical terms

Organization Charts and Manuals

FUNDAMENTAL CONSIDERATIONS.—In planning an organization and developing the charts and manual which graph and formulate its set-up—whether the procedure is for a new organization or a readjustment of an existing organization along more effective lines—it is necessary to keep in mind the basic requirements already stated, which may be summarized as follows:

1. The first fundamental is that **the organization must be built around functions,** not individuals. The activities or tasks which must be carried on should be blocked out following a typical or representative chart which carries the major functions normally necessary in most manufacturing enterprises. Modifications may be introduced at any point to adapt the chart to the particular company. There is no such thing as a standard chart of organization and no organization chart can be copied in whole from any other company, although it may be in the same industry or even in another plant of the same company. There are chart patterns but none which can be applied directly without alteration.

The main functions in a manufacturing concern are those of engineering, manufacturing, selling, purchasing, industrial relations, accounting, and financing.

2. **Functions which are closely related** must come under the same head.

3. When the major and related functions are thus distinguished and identified, they should be arranged so that each activity will be definitely provided for and all necessary duties may be properly performed.

4. In smaller companies—or in cases where the extent or the amount of work in some duties is limited—some such duties may be combined with others as closely related as possible, so that each such group can be handled by one person.

5. Only after such considerations have been settled should the question of persons enter into the picture. Since it is obviously impossible to secure in all cases individuals who are ideally qualified to handle the various functions or tasks, those who have most of the necessary qualifications are selected or engaged to take over the individual assignments. At this point it may be necessary to readjust the set-up so that the best results may be secured in performance. While some realignments may be necessary and certain usually unassociated activities may be delegated to the same individuals, two points should be rigidly adhered to:

a. The functions and subfunctions must be clearly identified and retained in the framework.

b. No assignments should be made which allow any two individuals to cross lines of authority and come into conflict. The authority and responsibility accompanying each function and subfunction, therefore, should be definitely delimited in the organization manual.

6. No more than 5 or 6 persons, in general, should report to an individual on executive or subexecutive level, where these subordinates, in turn, direct the work of others. Departments should be broken down into sections and the sections into units or groups, each headed by

capable assistants. Where immediate direction of workers enters, the limit to the number of subordinates reporting to the supervisor or foreman should be 10 to 15 in most cases. If work is highly routine or a large number of workers are engaged in repetitive work, the limit may be raised to about 20. It is better to break up any larger units into two or three groups, each headed by a leader who reports to the supervisor or foreman (Principle of Graicunas).

7. While it is desirable to limit the number of executives, supervisors, and foremen in a company, for reasons of efficiency and economy, no executive should be unduly overloaded with contacts and work. Especially in a growing organization, each executive should have some time for constructive planning and for growing in his job.

8. The organization plan should be developed with the idea of future expansion in mind, so that major reorganizations at a later period may be avoided.

9. All persons in executive capacity should have copies of the charts and manual and everyone in the organization should have access to these items at all times. There is nothing secret about the information. It is advisable to change all copies of charts and manuals, or at least issue change notifications, as soon as such shifts occur. At least the master copies should be promptly altered to keep them up to date.

10. Freedom of contact between all members of the organization for quick interchange of information and arriving at prompt decisions (Fayol's Principle) should be provided for in developing the charts and writing the organization manual.

11. Since no organization stays in a permanent form, it should be realized that frequent changes in the charts and manual will become necessary, beginning shortly after the original set-up is made.

ORGANIZATION CHARTS.—It is advisable, even in small companies, to draw up and post organization charts so that all persons may know how the various duties and activities are assigned and can find out where they fit into the set-up. While workers are not indicated in such charts, they know for which supervisor or foreman they work and therefore can see the relationship of their units or groups to the remainder of the company. In large companies it is necessary to draw a series of charts, starting with that of the top organization, which shows the relationships among officers and senior executives and the breakdown into divisions. A succession of charts then may show the organization of the respective departments and sections, in which intermediate and junior executives appear. A further breakdown then may graph the individual sections and units to indicate how authority and responsibility are carried down to supervisors, foremen, and group leaders.

In the breakdown charts it is helpful in each case to include a skeleton outline of the top organization to point out how authority from the president is delegated to the divisions, and then how the chain follows through the particular department, section, unit, and group down to the individuals to whom the workers report. If the spectator at a football game is interested in the organization of the teams he sees playing and the position that each man plays, how much more interested will the workman in a company be in knowing how the industrial team of which he is a member, and in which he earns his living, is organized and the positions which he and his boss play in the enterprise!

The drawing and revising of such charts requires considerable work and involves expense, but the trouble and cost are many times repaid by the benefits secured through broadcasting the information. It is likely that if a poll were taken of the workers in most plants, not 1% of them would know anything worth while about the organization set-up of their companies and the responsibilities which the executives, supervisors, and foremen carry. It is small wonder that, when the professional labor organizer vividly pictures the worker's position in the union and shows him what man heads up and carries on the union's relationships with the company, the employee feels himself closer to the union and more a member of it than he is of the company. The top executive himself, in a large company, unfortunately often has only a hazy conception of the interrelationships and sometimes very little of the detailed breakdown in his organization, but at least he knows the fundamental set-up and responsibilities, and he directs the enterprise, so that he can work through its channels. The worker, conceiving little of the importance of organization, usually is left completely at sea.

DRAWING ORGANIZATION CHARTS.—There are four typical ways in which organization charts may be drawn, as shown in Fig. 10. In this illustration, example (a) is most common and (c) is a variant sometimes useful for saving space. Example (b) is seldom used, while (d) is common in telephone companies—the blocks surrounding the titles and names often being omitted—and is often accompanied

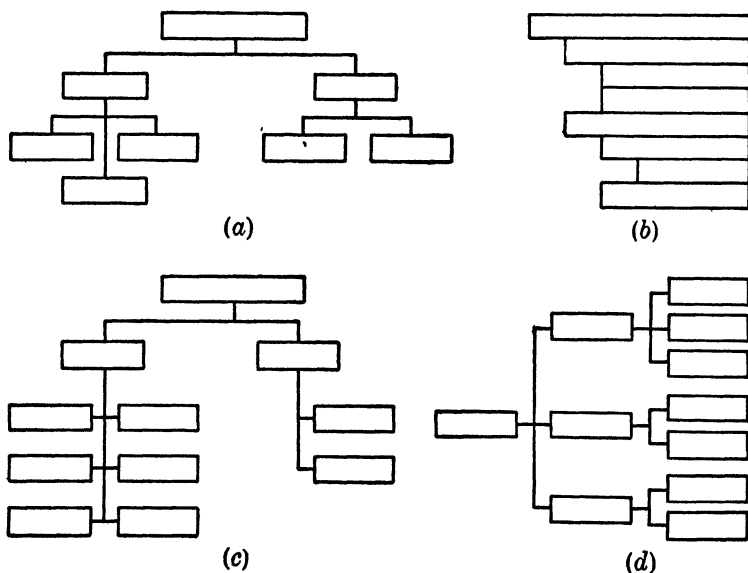



Fig. 10. Four Typical Ways of Drawing Organization Charts

by a statement of the total number under the direction of each executive at the successive levels.

EXAMPLES OF ORGANIZATION CHARTS.—The chart shown in Fig. 11 is typical of manufacturing plants in that it shows the principal functions and subfunctions usually provided for, and the range of work covered by the various departments and sections. As stated before, there are no standard organization charts, but merely representative charts which serve as guides in individual cases. This chart, however, merits careful study because of its comprehensive coverage of functions and the descriptive nature of its titles and the kinds of work indicated for the respective departments. The charts which follow may be compared with this representative set-up and will then be more clearly comprehended. It is seen that the names of individuals are not important in the building up of a chart, and have been omitted in the examples because obviously there will be changes occurring constantly in the personnel of the respective companies. In individual companies, for internal use, the names of persons make the charts clearer to the members of the entire organization.

Chart of a Separate Division of a Large Corporation.—In Fig. 12 is shown the organization chart of the Buick Motor Division of the General Motors Corp. The organization set-up was basically the same during the manufacture of war materials as during peacetime production of motor vehicles. This chart is reproduced only down to the level of factory superintendent, and to represent the fundamental plan instead of details. Five persons report direct to the president and general manager. The executive assistant to president and general manager has supervision over manufacturing, through a manufacturing manager and assistant manufacturing manager. The latter two men are in direct authority over nine division executives: director of personnel; master mechanic, whose responsibilities are plant layout, design and selection of machinery and tools, inventory of all machinery and tools, and all manufacturing processes; chief inspector; production manager, in charge of planning production; general superintendent; works engineer responsible for rearrangement of equipment, design and planning of new building, maintenance of buildings and machine repair, and supervision of the power plant; chief of standards; chief metallurgist; and superintendent of parts and service.

The general superintendent supervises the activities of the various factories in the division. He has two assistant general superintendents to one of whom 7 factories report and to the other, 5 factories. Each factory is headed by a superintendent. This chart indicates adherence to the functional principle and observance of the span of control—not too many heads of divisions for the supervisory executives to work with.

Organization Chart Constructed Horizontally.—Typical of the charts developed along horizontal instead of vertical lines, which are used to a considerable extent in the telephone field, are the two examples shown in Figs. 13 and 14, which are from the Chesapeake & Potomac Telephone Co. of Baltimore City. The chart in Fig. 13 is that of the division under the vice-president and general manager, which is a subdivision of the top management chart. The figures beside the titles of the various positions show how many people are within that part

STOCK HOLDERS
BOARD OF DIRECTORS
PRESIDENT
TREASURER
GENERAL MANAGER
SECRETARY
COMPTROLLER
CHIEF ENGINEER
WORKS MANAGER
SALES MANAGER
DIRECTOR OF INDUSTRIAL RELATIONS
OFFICE MANAGER
CHIEF AC-COUNTANT
COST AC-COUNTANT
ASST. CHIEF ENGINEER
ASS'T. SALES MANAGER
EMPLOYM'T MANAGER
PERSONNEL SERV. MGR.
SAFETY ENGINEER
GENERAL OFFICES
ORDERS FILING BILLING CREDITS COLLECTIONS MAILING TELEPHONES MESSENGERS VISITORS
ACCOUNT-ING DEPT.
BOOK-KEEPING CASH AUDITS INSURANCE FINANCIAL RE-PORTS AND GRAPHS
COST DEPT.
ORDER COSTS MONTHLY COSTS COST ANALYSES PAYROLL DETAILS OF FIXED ASSETS STATISTICS GRAPHS
ENGINEER-ING DEPT.
DESIGN OF PRODUCT DRAWINGS TRACINGS BLUE PRINTS DEVELOPMENT STANDARDIZATION SPECIFICATIONS BILLS OF MATERIAL ADVICE TO CUSTOM-ERS
SALES DEPT.
SALESMEN SALES CORRESPON-DENCE ESTIMATES PUBLICITY ADVERTISING NEW MARKETS
EMPLOYM'T DEPT.
INTERVIEWS SELECTION EMPLOYMENT TRAINING TRANSFER PROMOTION DISCIPLINE LABOR SUPPLY JOB ANALYSES JOB SPECIFICAT'NS RECORD OF EMPLOY-EES
PERSONNEL SERV. DEPT.
CAFETERIA REST ROOMS PHYSICAL EXAMINATIONS CLINICS SICK AID INVESTIGATION OF ABSENTEEISM FIRST AID HOUSING ATHLETICS
SAFETY DEPT.
SAFETY DEVICES FIRE PROTECTION FIRE DRILLS SAFETY, FIRE & SANITARY INSPECTION WORKMEN'S COMPENSATION SAFETY EDUCAT-ION

FIG. 11. Organization Chart of a Typical Manufacturing Company
(M. A. Lee)

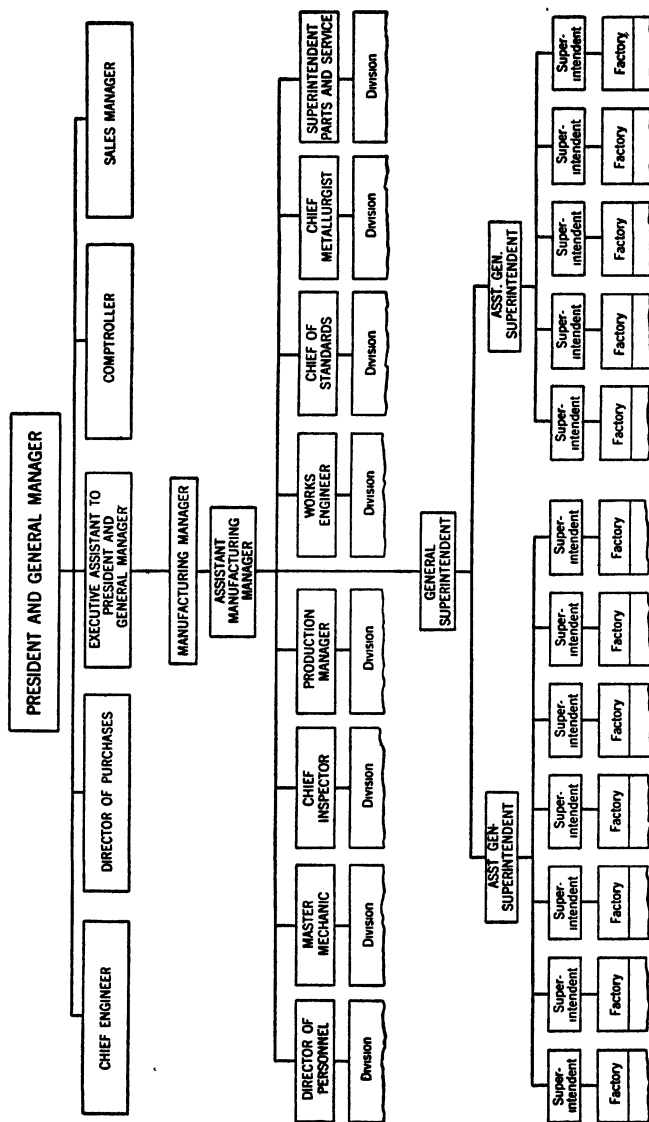



FIG. 12. Chart of the General Organization of the Buick Motor Division, General Motors Corp.

of the organization headed by the particular executive. In the actual chart the names of executives are included with the titles.

In Fig. 14 is the organization chart of the chief engineer's department, a breakdown of one of the departments in Fig. 13. The actual chart shows also the names of the persons holding the various positions. Where the bracketed notations "two individual executives," etc., appear, the names of these persons are given without specific titles. Note that the 33 persons under the chief engineer are accounted for by the 4 engineering executives reporting directly to him plus the 5 + 19 + 5 persons reporting to these 4 executives.

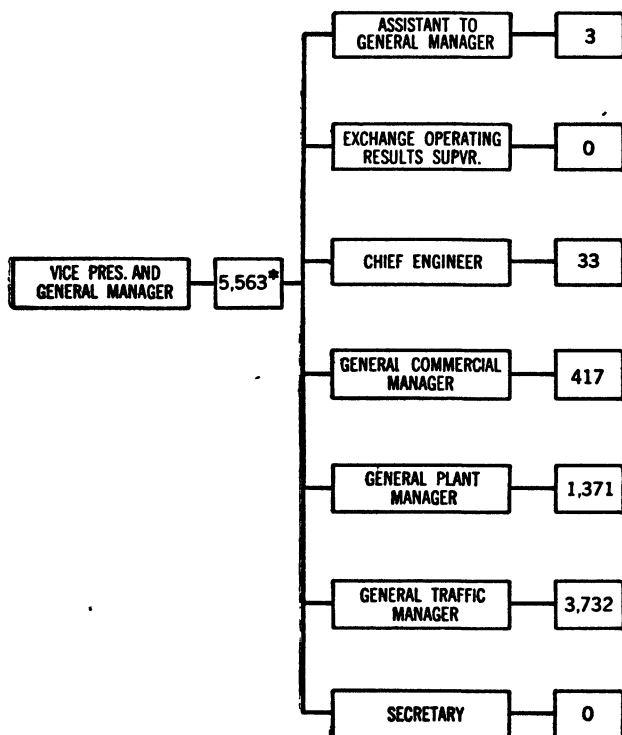
Aircraft Engineering Department.—A typical chart of the method under which the engineering departments of representative aircraft manufacturing plants are set up is shown in Fig. 15. Since the chief

* Includes 45 employees of the Virginia Company supervised by this Company, and excludes 593 employees of this Company supervised by the Washington Company.

Fig. 13. Organization Reporting to the Vice President and General Manager—The Chesapeake & Potomac Telephone Co.

engineer deals directly with executives and engineers of client organizations—Army and Navy officers for military and naval planes, and executives of airlines for commercial planes—he is made a vice-president of the company. An executive engineer is in charge of the actual operation of the engineering department in so far as facilitation of the work is

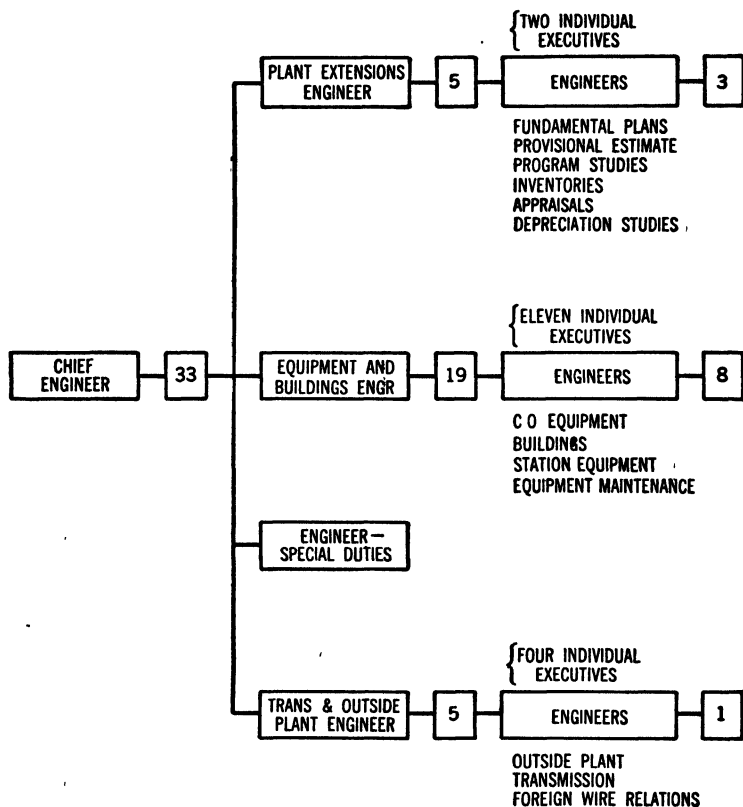



FIG. 14. Organization Reporting to the Chief Engineer—The Chesapeake & Potomac Telephone Co.

concerned. The staff engineers are specialists in fields such as aerodynamics, metallurgy, etc. Project engineers, like inventor-engineers in machine-tool companies, take over the handling of an order for planes and remain with it through all stages from design through tooling, manufacture, and acceptance tests. Their staff connection with design is shown by the dotted lines in the chart.

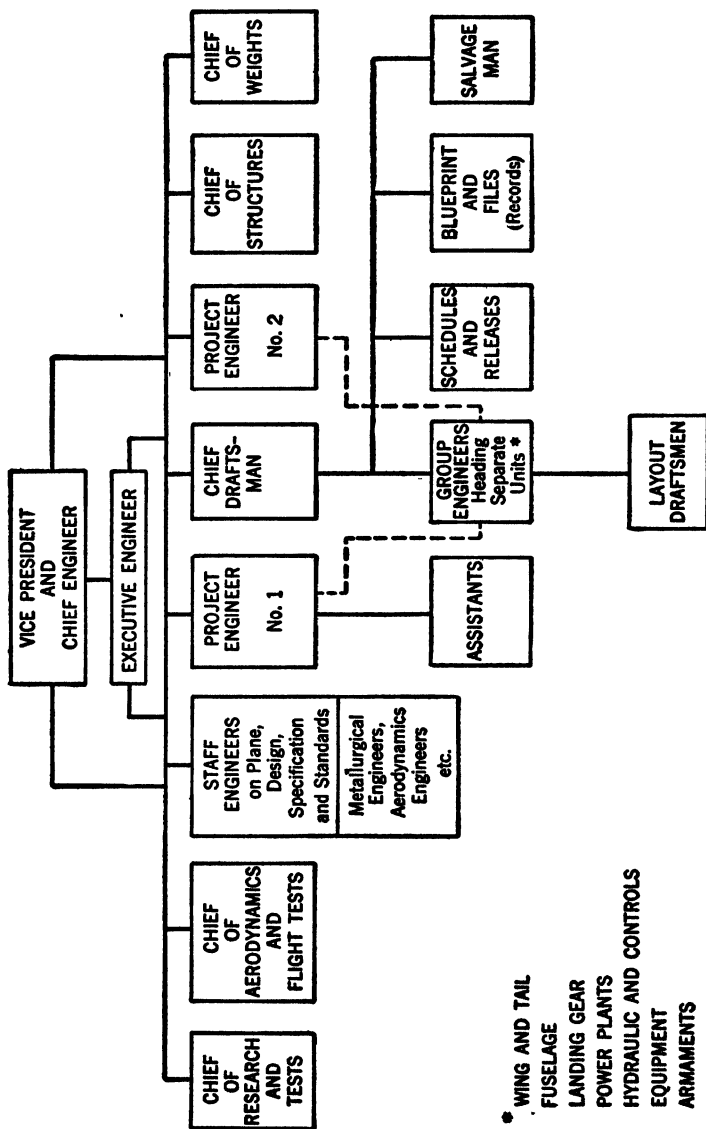



FIG. 15. General Plan of Organization of the Engineering Department in Representative Aircraft Companies

The chief draftsman is the operating executive in charge of the design section, in which there are usually about seven large groups—wing and tail, etc.—as shown. The chief of structures must approve all airplane structural features and the chief of weights must check all designs to hold down weights and maintain proper weight balance in the planes.

A Comprehensive Series of Company Charts.—One of the most comprehensive and thorough developments of modern industrial organization on sound and tested principles was carried through a few years ago in the Sperry Gyroscope Co., under the direction of its president, R. E. Gillmor. A complete set of charts, from the control organization down through the set-up of the individual plants, was developed and is kept up-to-date by a special staff whose members are continuously engaged in making the readjustments which are necessary to maintain the highest efficiency of operation. An organization manual likewise was developed to assign responsibilities definitely to the executives, division and depart-

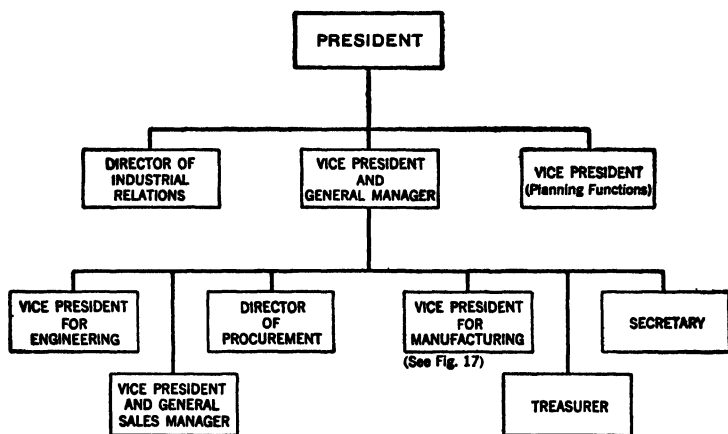



Fig. 16. Plan of Organization of the Sperry Gyroscope Co.

ment heads, supervisors, foremen, and staff members. This manual is also kept up-to-date in conjunction with the charts.

The plan of organization of the company is shown in Fig. 16, from which the names of individuals have been omitted. This chart shows that the central organization, headed by the president, is divided into six operating divisions and two staff departments. The operating divisions are: engineering, sales, procurement, manufacturing, treasurer's and secretary's. The director of industrial relations heads the staff covering all the industrial and personnel relations activities. The other staff department is headed by a vice-president for planning functions.

The plan of organization of the manufacturing division is shown in Fig. 17. This division includes the industrial engineering department, the production planning department, the general building and grounds de-

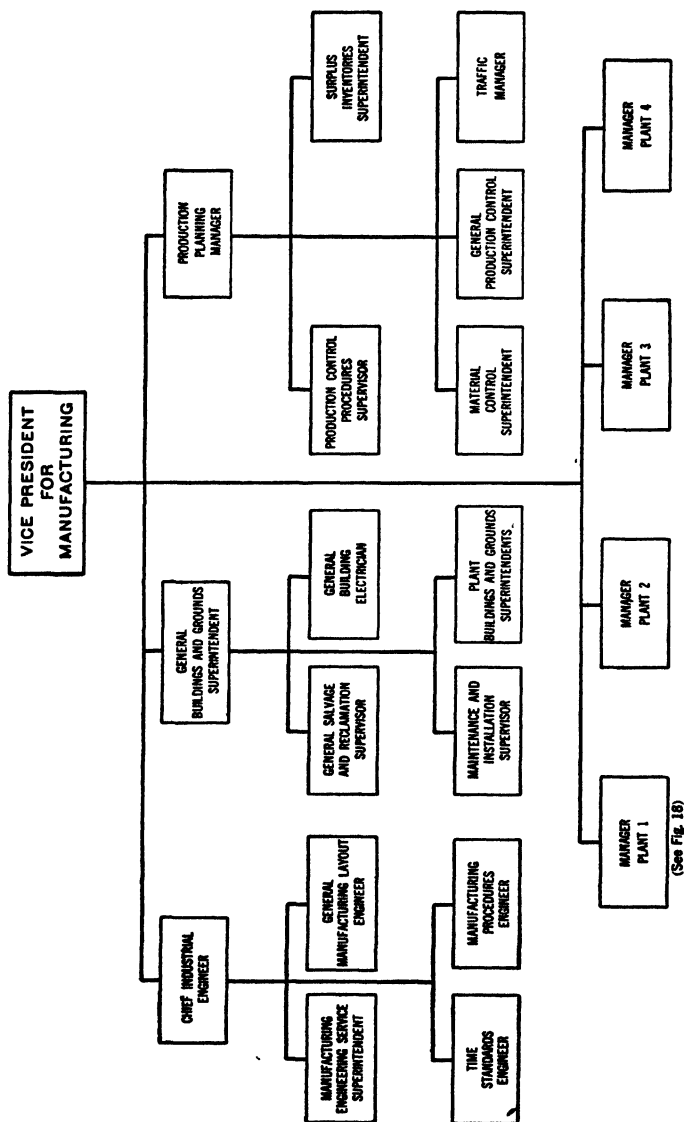



Fig. 17. Plan of Organization of the Manufacturing Division of the Sperry Gyroscope Co.

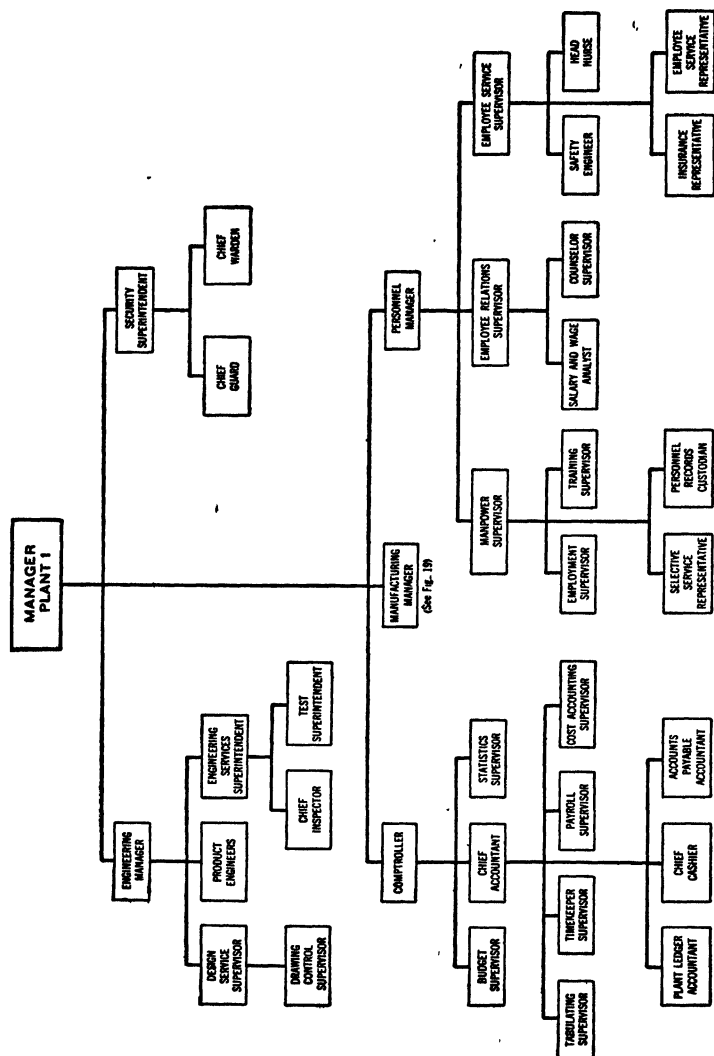



FIG. 18. Organization Plan of Plant 1 of the Sperry Gyroscope Co.

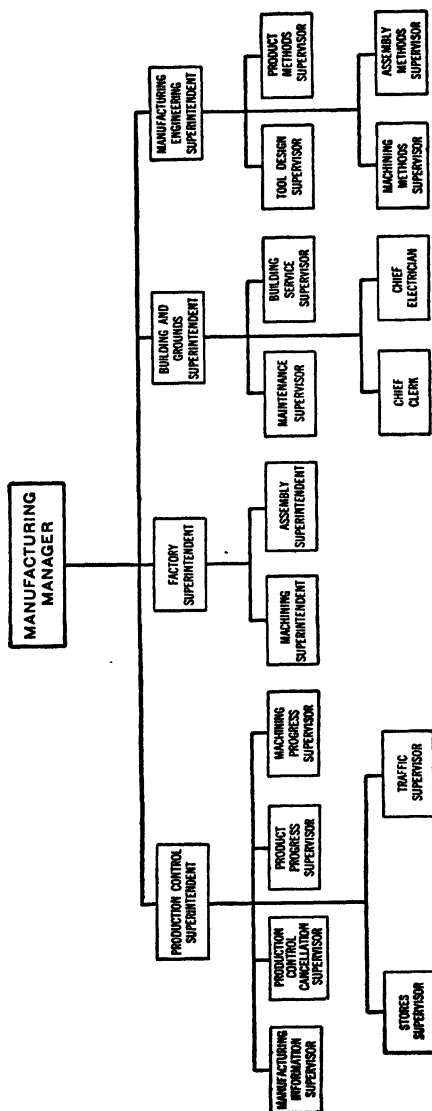



FIG. 19. Organization Chart of the Manufacturing Department of Plant 1 of the Sperry Gyroscope Co.

partment, and the manufacturing plants operated by the company. Plant operations are for the most part noninterlocking. The staff functions assist the vice-president for manufacturing in coordinating them.

The organization of one of the manufacturing plants (Plant 1) is shown in Figs. 18 and 19. Fig. 18 shows the nonprocessing departments. The plant is run as a unit of the company, having its own controller, engineering manager, manufacturing manager, personnel manager, and security superintendent, each in charge of these particular kinds of activities. Fig. 19 shows that the manufacturing department has its own methods engineering superintendent, production control superintendent, and building and grounds superintendent. The assignment of the various activities or functions and their relationship to one another are clearly shown in the charts.

THE ORGANIZATION MANUAL.—Organization charts give merely a picture of the organization and show the position of each individual in respect to others in the structure. Titles may indicate the nature of the work carried on by each person but often are misleading as to his real functions, because there is no general agreement among industries on the meaning of specific titles nor any attempt made in most companies to develop definitions for the various titles. A foreman in one company would rank as a superintendent in some other company, or in one case he might be over 5 men and in another over 200 but still be called a foreman. An organization chart, moreover, is static. It requires an additional medium to bring in the dynamic factor setting the organization in motion.

It is necessary, therefore, to develop an organization manual stating definitely the nature and extent of the authority and responsibility assigned to each position, so that the person filling it may know his duties, exactly what relationship he has to those above and below him, and the connection which his work has with that of men in other divisions or departments of the company. Even an organization manual cannot so specifically draw the borderlines so that there will be no questions on the above points. In addition, the continual shifting of the organization to take care of changes, and the new problems of operation which constantly come up, call for further explanations or some changes in the write-ups of the positions from time to time. Nevertheless, in the absence of an organization manual, even the smaller companies find that the various positions overlap, two or more persons are trying to handle some particular kinds of work, and certain other work is neglected, each person concerned with it leaving it to someone else to attend to.

The function of the organization manual is to set forth clearly the purposes which the manual is intended to fulfill, describe the general framework of the organization, state how it is broken down into divisions, departments, etc., state in general what are the different ranks or levels of authority—officers, division heads, department heads, etc.—indicate the difference between line authority and the staff function, define the terms used in the above explanations, and then give, for each division down through its successive breakdowns, the titles of the different positions in it together with the relationship of such positions to the immediately superior and subordinate positions and the range of responsibility, authority, and duties carried under the title. It thus defines the lines of authority and responsibility but cannot directly show the many

crisscrossing channels of contact between individuals in different parts of the organization. These are provided for according to Fayol's principle, given in a previous portion of this Section, in a general statement authorizing all individuals to secure aid or information from any proper source within the company.

Organization Manual to Explain Positions in the Charts.—The Sperry Gyroscope Co. Organization Manual typifies the effective manner in which such a handbook may be developed. In its introductory section it sets forth the fundamentals, definitions and explanations necessary to an understanding of the sections which follow later detailing the complete organization of each division. Indicative of the factors covered in the introductory section is the following statement:

All positions are responsible for:

1. Delegation of responsibility and authority in accordance with the Organization Charts and recommendations for improvements and modifications in such delegation.
2. Control of employment or release of any employees under them, subject to defined Industrial Relations Policies governing seniority, transfers, and similar procedures.
3. The coordination and discipline of all personnel reporting to them and the periodic rating of such personnel. "Discipline" is here used in its broad sense of complete conformation to every rule of conduct contributing to morale and efficiency.
4. The proper application of the principles and definitions of all accounts in the Accounting Manual relating to the operations for which they are responsible.
5. The proper application of all standard practice instructions relating to the operations for which they are responsible.
6. Training understudies to assume the position in case of promotion or absence.
7. Coordination of activities of the position with those of other positions.
8. The simplification and consolidation of all activities under them, and the elimination of such of those activities as are not essential.
9. Keeping currently informed on everything which will contribute to efficiency in the position.
10. Maintaining complete and easily available records and files of any information of future reference value and the disposal of such records and files after they have ceased to be of value.
11. Making any reports or returns required as a consequence of the activities under them and clearing such reports or returns with others concerned before their release.
12. Such duties in assisting others as are required.
13. The examination and approval, disapproval, or revision of all actions and recommendations concerned with the plans, facilities, scope, responsibility and policies of the position or those reporting to it. Examples are: expenditure authorizations; change in locations of departments; alterations in the structure of buildings; additions to personnel; changes in responsibility or compensation of personnel; price recommendations; stock orders; recommendations for changes in standard practice instructions. The responsibility for final approval in such matters, and the forms and procedures for obtaining such approval, will be specified by standard practice instructions.

Explanatory of committee organization and activities, the Sperry Manual introduces this section with the following statement:

Functions of Committees.—The functions of a committee should be confined to:

1. The dissemination of information.
2. The reconciliation of viewpoints.
3. The development of collective judgment on definite facts or proposals.

Except where specified, Committees exercise no executive power but are merely advisory agencies. Power to carry out the recommendations reported out of Committees rests either with individual members of the Committee or with individuals outside the Committee acting on the Committee's recommendations.

Each Committee should have a definite agenda and a capable agency to develop facts and present proposals preferably prior to meeting. Such an agency may be a secretary, a staff member, or one or more members of the Committee assigned for the purpose.

The Chairman, or in his absence the Vice-Chairman, is responsible for calling meetings, conducting them in an orderly manner following Roberts' "Rules of Order," and either carrying out or assigning the duty of carrying out such of the Committee's conclusions as he approves and which lie within his responsibility.

All Principal Officers are ex-officio members of all Committees.

In this section of the Manual the organization, functions and fields of the following committees are then stated: Research Planning Committee, Research Subcommittees, Production Planning Committee, Salary and Wage Administration Committee, Committee on Complaints and Adjustments, Committee on Suggestions, and Organization and Standard Practice Instruction Committee.

To avoid lengthy descriptions of duties, position descriptions are confined to definitions of boundaries of responsibilities. All terms employed in position descriptions are defined. These two factors make possible brief position descriptions. Illustrative of the detailed method in which the functions and responsibilities of the persons in the different positions are defined is the following extract from the Manufacturing Division organization section:

VICE-PRESIDENT FOR MANUFACTURING

Vice-President for Manufacturing—Line—Principal Officer (Division Head). Responsible to the General Manager for administering the manufacturing activities of the Company, including industrial engineering, production planning, building and grounds activities, and plant operations; the formulation with the General Manager and the Director of Industrial Relations of policies and procedures for industrial relations.

. . . . .

PRODUCTION PLANNING DEPARTMENT

Production Planning Manager—Functional Staff—Department Head. Responsible to the Vice-President for Manufacturing for all central organization production control and production planning activities.

Production Control Procedures Supervisor—Functional Staff—Section Head. Responsible to the Production Planning Manager for the development and unification of production control procedures, records and reports; and for the preparation and maintenance of the Production Control Standard Practice Instructions Manual.

Surplus Inventories Superintendent—Functional Staff—Department Head. Responsible to the Production Planning Manager for the control of all production scrap and material excesses, including accumulations, storage, and disposition.

Reclamation Supervisor—Functional Staff—Section Head. Responsible to the Surplus Inventories Superintendent for the designation, storage, and shipment of scrap surplus and obsolete production material.

Cancellations Supervisor—Functional Staff—Section Head. Responsible to the Surplus Inventories Superintendent for the preparation of inventory reports and shipments of all government claims production material.

Material Control Superintendent—Functional Staff—Department Head. Responsible to the Production Planning Manager for C.M.P. applications, development and dissemination of manufacturing information, control of raw material inventories, and the ordering of all raw materials and manufacturing supplies.

Raw Material Control Supervisor—Functional Staff—Section Head. Responsible to the Material Control Superintendent for maintenance of stock records, procurement, storage, and release to manufacturing of raw materials.

Manufacturing Information—Functional Staff—Section Head. Responsible to the Material Control Superintendent for preparing bills of material and manufacturing orders.

Inventory Control Supervisor—Functional Staff—Section Head. Responsible to the Material Control Superintendent for the maintenance of inventories at established standards of quality and quantity.

General Production Control Superintendent—Functional Staff—Department Head. Responsible to the Production Planning Manager for pre-production planning and scheduling; analysis of plant and departmental loads and maintenance of product statistics.

Planning Supervisor—Functional Staff—Section Head. Responsible to the General Production Control Superintendent for sales information, analysis of negotiations, and for issuance of shipping schedules.

Scheduling Supervisor—Functional Staff—Section Head. Responsible to the General Production Control Superintendent for the development of manufacturing plans, maintenance of progress records and load charts.

General Traffic Superintendent—Functional Staff—Department Head. Responsible to the General Production Planning Manager for planning all traffic operations of the Company; for operation of Company warehouses; and for furnishing transportation service to the Central Organization and the plants.

Warehouse Foreman—Functional Staff—Section Head. Responsible to the General Traffic Superintendent for the operation of Company warehouses, including the control and assignment of space therein.

Transportation Supervisor—Functional Staff—Section Head. Responsible to the General Traffic Superintendent for assistance in coordinating relations between Plant Traffic Departments and Central Organization units on matters relating to transportation.

Central Truck Dispatcher—Functional Staff—Section Head. Responsible to the Transportation Supervisor for operating the central truck dispatching depot for all Company trucks.

Car Garage Foreman—Functional Staff—Section Head. Responsible to the Transportation Supervisor for direction of the Inter-Plant Traffic Schedule and the operation of the Truck Garage.

Truck Garage Foreman—Functional Staff—Section Head. Responsible to the Transportation Supervisor for the operation of the Truck Garage; and for servicing transportation equipment for the Central Organization and the plants.

Detailed Statements of Responsibilities.—Some companies prepare manuals in which there is a detailed specification of the responsibilities borne by the executives and subexecutives. Typical of such a form of presentation are the following two delineations of the positions of production manager and factory superintendent:

The **production manager** is responsible to works manager for: planning and scheduling, due dates of all orders in all manufacturing departments; quotations and promises of delivery; supplying factory departments with statements of their machine and departmental loads; issue of all manufacturing orders and the papers and documents connected therewith; custody, control and maintenance of raw materials, purchased parts, and work in process; custody, control and maintenance of all small tools, jigs, fixtures, and gages; recommendations to sales department concerning stock orders necessary to maintain service to customers and continuity of factory load; forecasting shipments and reporting reason for changes therefrom, or departures from such forecasting; purchasing activities; packing, shipping, and routing finished goods shipped to customers; maintenance and control of all internal transportation; and for industrial relations within his division.

The **factory superintendent** is responsible to the production manager for: all machining and assembly work; forecasts of personnel required for the working force; recommendations as to the classifications of personnel for the various machining and assembly operations; recommendations as to additions, rearrangements and disposals of machine tools and factory equipment; recommendations as to changes and improvements in small tools; holding shop expense charges within budget appropriations; and for industrial relations within the factory departments.

STANDARD PRACTICE INSTRUCTIONS.—An organization is further implemented by what are known as standard practice instructions, which constitute write-ups of established procedures for the carrying out of various activities or the performance of certain kinds of work. Such write-ups constitute the "system" of the enterprise, but should not be allowed to degenerate into the class of unnecessarily complicated routines commonly called "red tape." It is readily seen that the organization chart tells "where" in the company a function is placed, the organization manual tells "what" the detailed nature of the function or position is and indicates its relationships to other functions and positions, while the standard practice instruction tells "how" the functions are to be carried on and the duties and responsibilities are to be discharged. It is necessary to have such procedures written up not only for the guidance of employees performing the work—so that it is all done according to instructions—and the training of new employees, but also because many of the important procedures cover several sections and departments some of which are feeders-in of information that others

must then compile and use in carrying on their work. Thus the procedure of handling time tickets covers not only getting the workers' time on jobs but also the checking off of completed work from production schedules, the making up of the payroll to pay workers, the charging of time to jobs or kinds of product to get current costs and record data for future estimating, and the posting of entries in the general accounts. In addition these time tickets form the basis for social security payroll deductions and taxation and reports to workers and to the government on earnings and withholdings. The time tickets are only one of hundreds of items for which standard procedures are not only helpful but also imperative.

The various divisions and departments may have handbooks in which these standard procedures are kept on file for frequent reference, copies being placed in the hands of executives and supervisors who are concerned with phases of such standard practices. Like charts and manuals, these write-ups must also be frequently checked and revised to keep them up-to-date.

Analysis of Organization and Procedures

ORGANIZATION ANALYSIS.—An organization, whether existing or in process of being designed, and particularly its procedures, can be submitted to detailed analysis. The methods used lead to simplification and standardization of duties or activities, methods and procedures. The end result is elimination of conflict and friction, reduction of waste of time and energy, quicker action in performing work, and lower costs. The analytic procedures involved, as formulated by Piacitelli (Society for Advancement of Management Journal) are:

1. Securing and recording facts.
2. Visualization of procedures involved.
3. Analysis of procedures.
4. Development of improved procedures.
5. Assignment of personnel to improved procedures.

Fact Finding.—Before a procedure can be analyzed it is necessary to make a **complete record of the facts and a clear statement of the problem,** in the light of the principal objective. All data with respect to what is done, who does it, sequence of the various steps, and their relationship to similar operations in other units, sections or divisions of the organization must be secured. In some cases the operation or examination can be described briefly in sufficient detail. In other instances the answer is obtained by a brief examination of the facts. In still other cases, and these are the most common, the problem is of a complex nature involving several individuals and many types of forms and paper work. In such circumstances a written record of facts would be so voluminous that the analysis of them would be unnecessarily involved. The Gilbreths developed a simplified method of visualizing such complex relations, using what they called "process charts."

Visualization of Procedures.—Process charts are a means of visualizing the various steps of a procedure or operation to indicate what is done, the order in which various elements are performed, their relationship one to another, and the individuals concerned. Certain elements

or steps are common to the performance of many operations. These elements are assigned **special symbols** so that they may be quickly identified. There are five basic types of symbols: the circle, triangle, square, rectangle, and halfsquare-semicircle.

1. The circle denotes an operation. Sometimes special symbols are used in it.
2. The triangle with its apex downward indicates storage. In office work it indicates a filing operation.
   The triangle with its apex upward indicates an activity outside the scope of the investigation.
3. The square indicates an inspection such as for quantity, for example, establishing the correct number of piece parts in factory, or checking a stores requisition to see if it indicates the correct amount of materials.
4. The rectangle denotes a form entering into the procedure which is being analyzed.
5. The halfsquare-semicircle, which with the square upward denotes transportation and on its side with the square at the left denotes a delay.

These are the basic types. Following this general plan additional symbols may be established to cover the particular needs and peculiarities of the work involved.

As the information pertaining to a procedure is accumulated it is recorded on a form in the order that the operations are performed and in their proper relation to such other work as may be done concurrently by other individuals. This visualization presents a clear picture of the procedure with respect to work done, forms or documents processed and personnel involved.

Analysis of Procedures.—The first step in analytical stage is to make a clear statement of the problem and examine the operation of the whole from the point of view of the objective of the organization. Such an examination sometimes shows that, although functional activities are necessary, the procedure is long and complex. In some instances the entire operation is found to be unnecessary and no further analysis is needed. In most cases the operation is necessary and each detailed step is critically examined for necessity and sequence. The questions to be asked and answered are these:

1. Are the steps necessary? If so, are they being performed in their most logical order?
2. Are all checks necessary, particularly the double checks?
3. Where else is work similar to this being done? Does overlapping of function and duplication of work exist? If so, where do these steps properly belong?
4. Are forms necessary? If so, are they the best that can be devised? Can two or more be combined into one?
5. Is the document or paper being routed through too many individuals? How many signatures or "surnames" are required for proper handling of that document?

The greater the number of people involved in processing a document, the greater the delay in getting desired final action. It is not at all unusual for a document, routed to about forty people and calling for about 10 man-hours of actual work, to require about 40 days to process. If, under a new procedure, only half of that number of people are

required to work on the document, the number of days is reduced in the same proportion, when hours of actual work involved are changed but little. Handling and rehandling the document through its many transfers from one location to another, is one of the greatest sources of delay in processing documents. Whenever possible, work found necessary should be concentrated in the hands of the fewest number of people.

6. Are documents unnecessarily registered in and out of units, sections and divisions?
7. Are dictated letters necessary, or would a form letter better serve the purpose?
8. Are there any parts of the procedure now performed in one section or division that functionally belong in another division?

In making such an analysis, problems of organization, functional activities, lines of authority, and degrees of responsibility often arise in such a form as to suggest a reorganization of the staff involved. At other times the analytical work points to a modification of policy.

Development of Improved Procedures.—The method of developing such procedures is similar to the methods applied for the analysis of work when making time studies and motion studies.

Once the new procedure is established a permanent record is prepared in the form of a standard practice instruction. This gives instruction for the improved procedure, fixes responsibility for the performance of each step involved, and assists in training the personnel in new methods. These instructions should show the steps to be performed, by whom they are to be performed, the sequence in which they occur, and the forms involved.

Assignment of Personnel.—With the completion of the instructions in the form of an organization manual, the next step is to determine the number of persons of each classification required for any given workload under the procedure. In making this determination consideration must be given to any work of a miscellaneous character, together with adequate allowances for absences and leave.

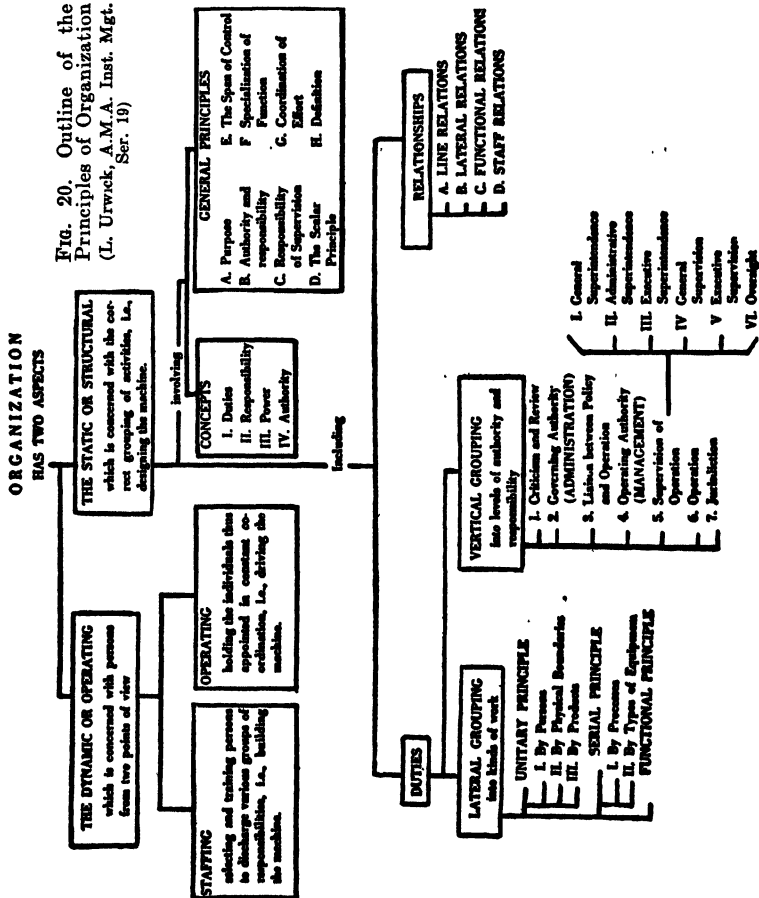
Involved in this step also is the determination of when additional personnel is needed in case of increased workload, and proper classification of the several individuals. Where such analyses have been made, little question will arise when additional personnel is needed to handle an increase in volume of work.

THE OVER-ALL PICTURE.—While it delves deeply into the principles of organization, the chart shown in Fig. 20 (Urwick, Scientific Principles and Organization, A.M.A.) presents a comprehensive picture of the factors and elements comprising sound organization and forms a practical basis against which to check the charts, manual, and standard practice procedures of any enterprise.

INSTALLING AND PERPETUATING NEW PROCEDURES.—Development of a new procedure is of little value if it is not made effective. This step is one of the most important elements in the problem. It is often relatively simple to determine an improvement or more desirable procedure. It is often another problem actually to get this procedure into operation. **Executive support** from top management is essential. Before a decision is made to put the improved pro-

cedure into effect it is desirable that it should be accepted by the various executives involved. Where there are honest differences of opinion they should be reconciled before the procedure is installed.

Once a decision to install is made, it is the responsibility of management to take proper executive action to bring about the desired change. Individuals involved should be given the proper instructions and the program should be watched carefully during the transition stage. Provisions should also be made for the perpetuation of improved procedures after they have become effective. A qualified person should

FIG. 20. Outline of the Principles of Organization (L. Urwick, A.M.A. Inst. Mgt. Ser. 19)

have the **responsibility for checking periodically** to see that they are being followed, and to make such adjustments as changing conditions may warrant.

INSPECTION OF POLICY AND ORGANIZATION.—The production organization of a plant employing a large number of workers is complex, and made up of many individuals, each with numerous duties. It is estimated that in every 100 individuals in a typical factory organization, 4 are major executives, 12 are supervising executives, and 84 are workers or wage earners. Because of this complexity, and continual changes in projects, methods and procedures, and the developments and evaluations which come about with passage of time, it is easy for an organization to depart from the policies, authorities, responsibilities and duties as they have been established. For this reason it is good practice to set up the function of **policy and organization inspection.** That is, someone should be assigned the duty of continually watching and observing the policies and organization structure, to determine when changes should be made and recorded, and if departures from the original plans need to be corrected. This function of inspection is no different in principle than the inspection of product. In the latter case the inspector determines the degree of conformance between the product as produced and the specifications therefor; in former case, the inspector determines the degree of conformance of operation with established policies, delegation of authority and responsibility, and allotment of duties as originally laid out.

EFFECT OF ORGANIZATION ON OPERATING RESULTS.—Fixing definite tasks and responsibilities in an organization is a requirement for satisfactory production control. Such determination likewise is a prerequisite to the personal efficiency of every industrial executive, supervisor and foreman. Only by removing all uncertainties and conflicts of responsibility and authority can a smooth-running organization be set up. Once established and maintained it must constantly be renewed to operate with a minimum of executive effort and to yield the lowest obtainable manufacturing costs. In this way the most can be made of both human and physical resources. The former include the personalities, strong points, training and experience of every member of the personnel. The latter comprehend the practical work of bringing together and directing the use of materials, tools, machines, equipment, working space, power, and all other physical agencies of production. Thus organization affects every activity in industrial operation, and is a powerful aid in obtaining economic results.

There is another aspect of organization always present in an industrial concern, unseen and intangible, but none the less real and existent. This aspect is sometimes known as the informal organization. It comprehends the endowments, character, and personality of the individuals who form the organization personnel. If the informal organization is good, functioning will be with less friction. Many of the activities of industrial managers are concerned with this informal organization, the interaction of persons, and the endless chain of effects that arise from human associations.

SECTION 2

PRODUCTION PLANNING AND CONTROL

CONTENTS

SECTION 2

PRODUCTION PLANNING AND CONTROL

DEFINITION.—Production control comprises organization, planning, checking on materials, methods, tooling, and operation times, handling of routing, scheduling and dispatching, and coordination with inspection, so that the supply and movement of materials, operations of labor, utilization of machines, and related activities of factory departments—however subdivided—bring about the desired manufacturing results in terms of quantity, quality, time, and place.

As a **principle of production control** Alford formulated the following statement (Laws of Management Applied to Manufacturing):

> "The highest efficiency in production is obtained by manufacturing the required quantity of product, of the required quality, at the required time, by the best and cheapest method."

The three divisions of production control are organizing, planning, and control.

FUNCTIONS OF PRODUCTION CONTROL.—Since no two plants are organized alike, and in many cases there is often no clear distinction between production control and actual manufacturing or operating—both being associated in the same personnel—it is necessary first to define specifically what functions belong under the category of production control and require provisions for proper handling. Moreover, the names assigned to production control departments differ, the kinds of work allotted to them are not alike among different plants, and the titles applied to the various positions or kinds of work carried on are not the same throughout industry. A further set of complicating factors arises under the mistaken impressions that, first, there are numerous varieties of production control, second, that there are definitely standard systems which apply directly to different kinds of industries and, third, that set-ups can be copied bodily from other factories and, when thus introduced will work with corresponding success. Organized production control is necessary for the most successful operation but the methods installed must be built along the proper functional lines and must be definitely **adapted to the particular plant** in which they will be used.

Production control is a facilitation service to manufacturing, preparing the way and supplying all the necessary production information and aids, including methods, times, materials, and tools, directing and checking on the course and progress of work, and closing the records upon accomplishment of the jobs or the filling of the manufacturing orders. It has sometimes been called the "paper work" of manufacturing, although this term is too limited to cover all of its duties. In general,

it has relieved the superintendent of manufacturing of nonoperating responsibilities and has removed from the foreman the burden of preliminary planning and follow-up and recording duties, leaving him free to concentrate on his three most important tasks—getting work done, developing his workers, and handling labor grievances.

An inclusive list of the **functions or duties** which may come under production control comprises the following activities:

1. Job planning.
2. Production orders and forms preparation and issuing: work orders, time cards, move orders, materials issue slips, tool issue slips, etc.
3. Stores record ledgers.
4. Purchase requisitioning to
   a. Replenish stores regularly carried.
   b. Obtain special items bought outside.
5. Methods engineering, operation analysis, etc.
6. Operation lists and route sheets.
7. Tooling for jobs.
8. Time and motion study.
9. Instruction cards.
10. Wage rate setting.
11. Work scheduling.
12. Machine loading.
13. Work dispatching.
14. Storeroom operation.
15. Tool crib operation.
16. Finished stock control.
17. Receiving.
18. Inspection of incoming materials for quantity and condition.
19. Shipping.
20. Job estimating (for quotations).
21. Production records.
22. Standardization of operations, routing—in coordination with other departments—of tools, materials, etc.
23. Internal transportation.
24. Expediting of manufactured items and purchased items.
25. Subcontracting control.
26. Idle machine analysis.

Not all these activities will be handled by production control in every company but all come within the facilitation or service functions which must be taken care of somewhere, with the majority of them most successfully handled in a well-organized production control department.

The **spread** of production control department functions will depend (1) on the nature of the business; and (2) on the way in which organization activities are divided. In some industries an engineering department prepares fundamental data. Drawings, blueprints, specifications of material and of operations on each piece, lists of parts, inspection standards, and similar technical data are usually prepared by this department, where there is one. Sometimes a "research" department is maintained, continually studying improvements in product. In other industries the starting point is a pattern or model, such as printer's copy, or a foundry pattern. It may also be merely a sketch or drawing from which a model or pattern is prepared. Plants making stamped, pressed, or molded parts, foundries and concerns handling small repetitive work for customers come into this category. In chemical processes the starting point is a formula or series of formulas, with data on materials,

purity and quality and quantity, temperatures of processing, and other control data.

How much of this work falls to the production control department will depend on the method of organization. Properly such design work should be entrusted to a special department corresponding to the engineering department. But if not thus assigned, the production control department will have to deal with it. In one department or another, some one must analyze the proposed product into its components, determine the quality and quantity of material, specify standards of quality for the product, and provide all the necessary technical basic data on which the actual planning may rest securely. So-called "simple" systems are not infrequently described, but on examination it will usually be found either that the product is one requiring but little planning, or, more often, that some of planning and control functions are being performed by other departments under other names. On the other hand, technical data and their preparation, and even the layout of machines and conveying systems, are sometimes called planning. Much confusion in nomenclature exists.

Planning

PLANNING PRODUCTION.—The planning phase of production control consists of the systematic predetermination of productive ends —products and services—and of the means—methods and procedures— necessary for the accomplishment of these ends in the most economical manner. It implies the most efficient expenditure—in combination— of time, human energy, and material resources.

Principle of Planning.—Planning implies **systematic** mental work on problems of production. The principle of planning reads (Alford, Laws of Management Applied to Manufacturing):

> "The mental labor of production is reduced to a minimum by planning before the work is started, viz., **what work** shall be done; **how** the work shall be done; **where** the work shall be done; and **when** the work shall be done."

Planning may also be defined as:

> The technique of foreseeing or picturing ahead every step in a long series of separate operations, each such operation to be of maximum efficiency, and of so indicating each step that routine arrangements suffice to cause it to happen in the right place and at the right time.

IMPORTANCE IN RELATION TO THE PRODUCTION PROCESS.—The necessity for careful planning of production operations arises from four important factors:

1. Modern production has become increasingly complex, requiring systematic "thinking through" of the process in advance.
2. Production processes always involve the element of time in varying degrees. In the initiation of production anticipation of probable future utilities and calculation of probable future costs are essential.
3. The element of probable change must always be taken into account.
4. Successful production aims at the most economical combination of resources, which requires planning as a means of effecting cost control.

Complexity of Planning Functions.—The relative complexity of modern production is caused chiefly by the division of labor, or specialization, both at the executive level and in the factory. Division of labor, within limits, promotes economy through increased productivity per man-hour but is always attended by a correspondingly increased difficulty of coordination. Efficient production is rarely achieved by the voluntary cooperation of specialists acting on their own initiative. It must be brought about from above through working out of a preconceived plan. The principle involved may be stated as follows:

> "When production is divided into separate operations, coordination is most effective through definite directive agency."

Influence of the Time Factor.—All productive processes require time for completion. Elaborate preliminary preparation for production is necessary over a long period and often means large fixed capital investments. There is great danger of misjudging the demand when such investments are being made long in advance. Producers tend to overshoot or undershoot the mark, leading later to apparent overexpansion and idle plant capacity or, on the other hand, failure to provide enough facilities and therefore the use of wasteful emergency production measures.

Provision of **fixed property and specialized plant** are not the only long-term commitments requiring careful anticipation. **Recruiting of personnel,** development of specialized skills, establishment of harmonious working arrangements, and building of organization morale, often require an investment as substantial and always as essential as investments in plant. These factors require planning even though they are not fully reflected in the balance sheet.

The **short-run factor,** which is the chief consideration involving time in the current planning of production, relates to the interval required to complete one cycle of the production process. Production planning is primarily concerned with the planning of inventory investments in raw materials, work in process, and finished products with a view to meeting necessary requirements with the least cost. Planning failures on short runs therefore are reflected chiefly in maladjustments in inventory investments. While mistakes are less serious than those in long-run predictions they nevertheless may be responsible for considerable waste.

Change as a Factor.—The necessity for anticipating requirements during the time required for completion of the production process makes planning imperative, but it is the continually changing demand that makes the task of planning difficult. The factor of change manifests itself in a variety of ways. Sometimes it occurs with sufficient regularity and frequency to show an underlying rhythm. Sometimes long-time trends can be discovered and therefore predicted with a reasonable degree of certainty. Often qualitative as well as quantitative changes in demand are important. **Qualitative or style changes** are associated with consumer reactions and therefore affect chiefly, though by no means exclusively, manufactures of consumers' goods. Consumers are highly imitative and manufacturers of the less ingenious type are quick to follow style leaders. Thus progressive producers must be continually changing their products if they are to hold their customers. The task

of making adjustments is in large measure a marketing problem but introduces, nevertheless, a disturbing element contributing greatly to irregularities of production schedules.

Secular changes are upward or downward trends over a long period of time and often are traceable to some profound technological or competitive disturbance which affects the interests of the enterprise adversely or favorably as the case may be. They play a large part in the long-run investment plans of industry but do not fall within the scope of short-term production planning.

Cyclical changes include not only fluctuations ordinarily associated with the ups and downs of the business cycle but also seasonal changes and even weekly and daily fluctuations. In so far as the business cycle is concerned the problem of production planning is one of foreseeing significant turns in business activity with sufficient accuracy to avoid maladjustments in inventory investment.

In determining the manufacturing program a full knowledge of the operating history of the business is essential. When a concern has been established for a period of years, sales and production can be forecasted with reasonable accuracy, but current conditions must also be taken into account. Forecasts of general business conditions are made by several statistical organizations and can be blended with the firm's own experience. Large concerns now frequently maintain statistical departments for the collection and working up of data throwing light on the possible business trend, with special reference to the industry in question.

When the production program has been formulated, it becomes the task of the production department to reduce it to working data—dates, times, and quantities, in regard both to materials and operations.

Seasonal fluctuations may be predicted with reasonable certainty since the causes lie in the changing seasons, which occur with regularity. Fig. 1 shows the way in which current production may be adjusted to provide for seasonal demand. The production line is held uniform at

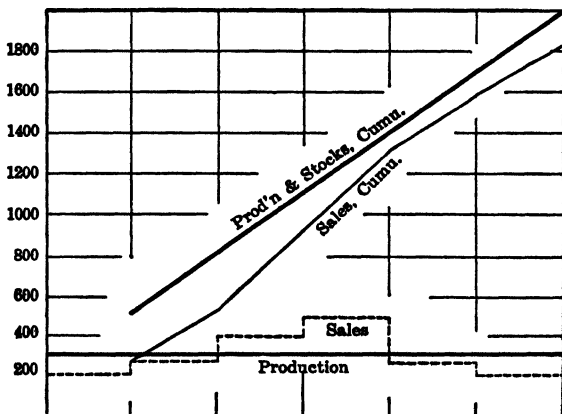



Fig. 1. Adjusting Production to Seasonal Sales

300 units per month. Sales vary from 200 at the beginning and end of the period to a maximum of 500 units toward the middle of the period. There are in stock 200 units at the beginning of the period, and cumulative lines show the relation of production and stocks to product sold. It begins and ends with 200 in stock, and keeps ahead of sales, although at the end of the peak period only 50 units are in stock. This margin might or might not be considered safe. If not, then overtime would probably be indicated as the peak period was being passed. The dependence of steady production on intelligent forecasts of sales is shown by this diagram. Unjustified optimism leads to unnecessary production, and this later to unnecessary curtailment and perhaps loss of possible sales. A close forecast, rather under than overrealization, permits of the most efficient production. Overtime can be worked if the forecast was a little too low, but to curtail output means greater risk of loss.

Weekly and daily fluctuations are important chiefly in industries producing perishable products or services which must be supplied at the instant demand develops. This situation presents a highly specialized problem of production planning in public service agencies such as power, light, and gas companies. The problem of planning and control in such instances consists chiefly of maintaining suitable standby equipment which may be cut in when required and cut out when peak demand periods are passed.

Planning in Relation to Cost Control.—Planned production is necessary as a means of waste elimination and cost control. Until plans have been formulated costs cannot be predicted and without cost standards management lacks suitable criteria for judging the efficiency of the production process.

In making plans with reference both to current and long-term operations management must give attention to three main kinds of cost: (1) **operating costs** which are approximately proportional to volume of current production; (2) **shutdown or "fixed" costs** which must be borne even though the volume of production were temporarily to be reduced to zero; and (3) **abandonment cost** which cannot be escaped even if operations were to be permanently abandoned.

ANALYSIS OF THE PLANNING PROCESS.—The production planning process includes three phases:

1. Research and exploration. Concerned chiefly with the definition of issues to be included within the scope of the plans and the determination of various possible alternatives which may be employed in achieving the desired ends.
2. Choice of resources, facilities, methods, and procedures to be employed.
3. Codification of plans. Including formulation of **specifications** covering products and materials, tools and manufacturing facilities which are necessary for performing the job; **objectification of plans** including drawings, models, layout charts, and similar devices which are required in delivering the plans to those who will carry them out; **formulation of procedure** and instructions as to how plans are to be placed in execution.

Adapting Planning to Fundamental Conditions.—Planning must be adapted to the production conditions under which it is to be applied.

While there is a basic pattern according to which any production control organization must be developed, and there is a basic line of procedure which all production control activities must follow—whether the planning is all mental and unrecorded or, at the other extreme, whether the most elaborate system must be set up for the purpose—in all cases both organization and procedures must be specifically adapted not only to the kind of industry but also to the specific plant or shop. The apparently wide difference between the method of planning and operation in one company and another arises solely from the way in which the production control activities are necessarily carried on, not from fundamental variations in the "what, why, when, where and how" of such activities. The so-called systems or types of production control represent adaptations and should not be regarded as totally different conceptions of the functions and procedures.

FACTORS DETERMINING PLANNING AND CONTROL PROCEDURE.—The procedure of planning and control of production is determined by several **conditioning factors**:

1. General plan of organization with reference to degree of decentralization of performance.
2. Nature of manufacturing processes.
3. Variety and repetitive character of operations.
4. Magnitude of operations.

Decentralization of Performance and Control.—The degree to which the performance of any activity must be decentralized depends upon the scope of operations and the convenience of their location. In large factories activities associated with storeskeeping, processing operations, and custody of finished goods must of necessity be carried on in numerous locations either within a single plant or in a number of branch plants sometimes located at widely separated points.

The issue then becomes one of determining whether authority and control over these various operations shall be decentralized or centralized. Coordination is most effective when authority is centralized. When performance must be decentralized, however, to centralize authority and control requires devising a means for effecting remote control.

Planning and control functions with reference to scheduling times, prescribing methods, and specifying quantities must of necessity be centralized to insure unity of action and to avoid duplication of effort, but must also be accompanied by decentralized means of transmitting orders and compiling information as to the progress in carrying out these orders at the various points where actual production is carried on.

Nature of Manufacturing.—The degree to which production control is developed varies with different industries. It is at a minimum where a single homogeneous product is treated by a fixed sequence of processes. Modern examples on a vast scale are afforded by paper, pulp, and rayon yarn industries. Flow sheets in these industries exhibit a continuous stream of product on which many operations are performed, materials added, and byproducts or wastes eliminated, but without break in flow or exceptions in work or processes. Very little planning is required in such industries, since it has already been embodied in the equipment itself. On the other hand, a very high and exact development of the in-

specting function is demanded, each stage of operations being controlled in the most scientific manner available.

Contrasted with a continuous industry are repetitive operations in a plant making automobiles, typewriters, sewing machines, and similar complex mechanisms. Here a great variety of material is used in many ways and for many purposes. There are hundreds or even thousands of parts, on each of which one or many processes take place on a diversity of machines. To bring together in proper sequence and at the right time and place the results of such complex activity taxes planning and control functions to the utmost. The situation is yet more difficult if custom orders are intermingled with manufacturing for stock.

In **custom manufacturing,** less accurate prevision is possible than when manufacturing for stock. In many cases, however, it is possible to forecast probable business rather closely, based on past experience and known trade conditions. While definite scheduling is not possible, the raw material situation can be surveyed in the light of probable demand. Custom orders usually require a certain time to pass through the plant over and above actual operating time. This time lag gives opportunity for planning, scheduling being effected immediately on receipt of order. In some industries, as in certain textiles, orders are taken on samples made up in advance of the season, each sample being accepted by many customers in varying quantities. When the bulk of such orders are in, a consolidation is made, and the yardage of each pattern found. These orders are then treated as though being manufactured for stock.

In **mixed stock and custom manufacturing,** either stock or custom orders may be the main feature. The routine will vary somewhat. If the former situation prevails, surplus machine capacity is ascertained from machine load charts, and custom orders are scheduled to absorb it. If the custom manufacturing preponderates, the reverse is done; stock manufacturing is fitted into whatever surplus machine capacity is left over from custom work. The first course above may mean slow delivery of custom orders, the second an uncertain output of stock. A middle course is generally advisable, stock production being interrupted at times convenient for custom orders, yet not so often or at such moments as to hinder efficient output. A certain amount of stock manufacturing to fill gaps in machine loading is a useful accompaniment of custom work.

Varied and Repetitive Operations.—In general, variety of operations complicates the problem of planning and control, whereas repetitive operations, since they reduce variety, tend to simplify the problem. In practice there are all sorts of variants between these two extremes, represented by the continuous production of a single standardized product on the one hand and the completely special-order business on the other. Some of the **principal variants** are:

1. Manufacturing to orders, which may or may not be repeated at regular or irregular intervals. Examples: jobbing foundries, printing plants, bleaching and dyeing, jobbing and repair machine shops, manufacturers of locomotives, conveying machinery, large special machines in general, and machine shops that contract for batches of product for other plants.
2. Manufacturing for stock, under repetitive or mass production with some choice between processes, and with assembly. Examples: automobiles, watches, clocks, typewriters. Custom orders may be inter-

mingled with repetitive work, but this plan is not now considered good practice, if avoidable.

3. Manufacturing for stock, where the product is made up of parts but the processes are not optional. Examples: shoe manufacture, garments, and many other nonmachine-shop type industries. Custom orders may be intermingled.
4. Manufacturing for stock, under continuous process manufacturing. Many chemical and food products, glass, soap, paper pulp, rayon yarns.

Factors tending to a **complex control system** are:

1. Number of ultimate parts in the product.
2. Number of different operations on each part.
3. Extent to which processes are dependent, i.e., those which cannot be performed until previous operations have been completed.
4. Variation in capacity of machines for different classes of work. In many industries speed of machines varies according to the nature of the material being worked on.
5. Degree to which subassembly exists.
6. Degree to which customers' orders with specific delivery dates occur.
7. Receipt of orders for many small lots.

Factors tending to **simplicity of planning and control** are:

1. Degree to which repetitive work occurs, i.e., when the same work is done over and over again in the same way, preferably in cycles.
2. Absence of special dates for special items, as when everything is made for stock.
3. Fixed capacity of machines or processes.
4. Invariable method of operation of machines or processes.
5. Absence of discrete parts and assemblies.
6. Completely balanced production, in which capacity of every process is strictly proportional to flow of work.

Magnitude of Operations.—Scale of operations has an important bearing on the nature of the problem. In the small-scale enterprise planning and control may be more informal because more personal and direct. As an enterprise increases in size new techniques must be devised.

Landry conceived the whole process of planning, especially in machine-shop or engineering types of industries, to be divided into nine separate functions:

1. To study design from a manufacturing standpoint and prepare a cost estimate.
2. To prepare manufacturing drawings and blueprints.
3. To determine kind and quantity of raw materials required.
4. To plan manufacturing process.
5. To design and provide tools.
6. To provide machinery.
7. To prescribe grade of labor required.
8. To establish time or output standards.
9. To prescribe wage payment plan.

This program contemplates the setting up of the best procedure even though involving a large expenditure on special machinery as well as tools, jigs, and fixtures.

In the ordinary plant, the products of which respond merely to an established, normal demand, the outlook is usually somewhat more re-

stricted. New, specialized machinery must be adopted cautiously. Tools and fixtures must be so planned that their cost is recovered before they are obsolete or worn out. It is easy to tie up large amounts of capital in patterns, jigs, and auxiliary equipment which become practically "frozen" because of insufficient use. Yet with this proviso the operations of the moderate-sized plant will be found, on analysis, to correspond closely with the divisions of manufacturing above cited. Modern practice tends to emphasize the planning end, that is, to bring into prominence items 1, 3, 4, 5, and 8 in the list.

TYPES OF PRODUCTION PLANS.—Types of production plans include: (1) those relating to **quantities** and synchronization of production operations with sales requirements; (2) those relating to **method**; and (3) those relating to detailed **timing** of elemental production operations necessary for achieving the desired final result. The first type relates to the production budget, while the second and third relate to current production operations necessarily involved in putting the budget into effect.

Plans Which Prescribe Quantities: The Production Budget.—Modern practice demands that prevision be exercised as far as possible in all matters relating to future expenditure, including that on production. The latter is developed through what is termed a "production budget." One object of this budget is control of overhead expense, but the only aspect which is of concern here is the method of reconciling actual production with estimated sales requirements in a coming period. It is, therefore, a manufacturing program that is in question, determining the volume of production each week or month for a period of several weeks or months ahead.

While production planning deals with ultimate detail, a manufacturing program deals only with broad quantities and times. Its principal aim from the production standpoint is to maintain production at as near a uniform level as possible. While sales may fluctuate seasonally, it is often possible to plan production on more stable lines.

To give effective cooperation, the sales budgets should be expressed in quantities as well as values. Variations in demand from month to month should be shown. In breaking down the corresponding production budget into components, a sharp distinction should be made between components produced in the plant and those purchased or purchasable outside. It is usually the former which are the limiting features of possible output.

Plans Which Prescribe Method.—Operation planning and routing come under the category of planning done according to method. It is important to note that the division between mass production control and custom order control begins here. In the first case, operation and routing plans, once made, are standard until a modification in processing is determined on. They are good "until further notice" and are usable over and over again. In **repetitive work,** operation and sequence planning should be considered as a preliminary to actual production, just as materials control and machine analysis are preliminary. In very large plants they are actually preliminary. Before putting a new product into manufacture, every detail of operation and sequence is fully decided and reduced to written instructions. Data thus assembled remain good until

some change is seen to be advisable. Otherwise the data are available, without further study, whenever a lot of the same kind is put through. It is merely a question of being filed for instant reference.

In custom work, on the contrary, every new order requires its own special operation and sequence study. Nothing can be done until the order is received. Work then done cannot be directly utilized a second time unless it happens that the precise order is duplicated at some future date. This fact implies that a more extensive organization must be maintained to handle operation study and sequence planning for each new order as it comes in. Data to be assembled will be much the same as for repetitive work, but as the data may be used only once, less elaborate time study is indicated and the use of past records in connection with the tabulated machine analysis should be substituted wherever practicable.

Current planning that prescribes method is made up of the following steps:

1. Production analysis of material.
2. Production analysis of operations.
   a. Determination of best method.
   b. Determination of operation time.
   c. Determination of operation sequence.
3. Determination of lot sizes in repetitive manufacture.

Operation planning, it will be noted, prescribes time allowances for each operation, since such time is intimately connected with the method of doing the work. Operation times and sequences are basic information on which current planning according to dates and times is built up.

Plans Which Prescribe Dates and Times.—While it is true that machine analysis and operation study have certain byproducts of value, notably in relation to piecework prices or bonus rates, their main objective, from the standpoint of production control, is reached in the setting up of a working time-table of shop operations, to which, moreover, strict materials control contributes an indispensable factor. The objective is the same in all plants, large or small—that of distributing physical materials to various processes so that:

1. Every order shall be executed in the shortest possible time.
2. Promised dates of delivery shall be based on definite information.
3. A constant supply of work shall be kept ahead of each process or machine.

In planning production an important pivotal point requiring the most careful coordination is the fixing of the shipping or delivery date, which will fit the requirements of the sales department on the one hand and the capacity of the manufacturing department on the other. William B. Cornell points out that friction can be ironed out, mutual understanding and cooperation fostered through carefully arranged conferences between representatives of the two departments; and that these representatives should be men who can be relied on to discuss problems fairly and reasonably, men not overly cautious or overly optimistic, who base their decisions on facts rather than emotion.

GENERAL PROCEDURES IN PRODUCTION CONTROL.—The general procedures followed in production control are presented here with accompanying explanatory data. Essentially the same funda-

mental channels and procedures are followed in all industries, regardless of size. The **ways of carrying them on are varied** according to whether the plant or shop is engaged in (1) continuous standardized production, as in the chemical, cement, flour-milling, or similar type industries; (2) lot repetitive standardized production, as in aircraft, automobile, radio, shoe, and corresponding industries; or (3) job-shop nonstandardized production where practically every order is different in many respects from every other order going through at the time. The detailed manner of procedure is varied likewise according to the size of plant because small factories obviously cannot have separate sections for all the branches of production control, such as are necessary for efficiency in moderate-sized or large plants. One or a very few individuals must absorb and perform all the functions.

Furthermore, manufacturing operations carried on under mass production can be simplified, mechanized, and streamlined, and production planning and control procedures applied under such advantageous conditions can be likewise shortened, telescoped, and streamlined, cutting down vastly on the personnel needed and the forms and amount of paper work required. Unless these facts are clearly understood it is difficult to develop plans for organizing and operating the work of production control. Mere copying of individual forms and isolated portions of systems in other plants results in confusion and inefficiency.

Relationship of Production Control to Other Departments.—The diagram in Fig. 2 shows the principal relationships between the production control and other departments in the plant.

1. (Refer to numbers on diagram.) Assuming that the plant is not purely a job-shop, a sales budget forecasting the volume of business for the coming year or half-year is prepared by the sales department.

2. The production budget, based on this sales budget, is then worked out with the production control section of the manufacturing department, usually forecasting monthly quotas of production. This production budget, when passed on by the management, constitutes the authority for the manufacturing department to proceed.

3. Technical data concerning the product are prepared by the engineering or other technical departments. They frequently consist of drawings, drawing lists, parts lists, or bills of materials, specifications, inspection standards, etc.

4. Stores records or balance-of-stores ledgers are consulted to find out whether the required materials are on hand and available. These records are kept preferably in the production control department rather than in the storeroom, are thus immediately accessible, and are promptly posted with receipts and issues so that available balances are constantly known. Reservations or apportionments, in the form of deductions from stores available, are made to take care of orders which are being prepared to go into manufacturing. Stores issue slips are often made out from which apportionments are posted. Supplies of such stores are replenished, when reaching predetermined points, by placing requisitions with the purchasing department.

5. Purchase requisitions are placed for all items or materials not carried in stores. The time required for placing purchase orders and securing delivery is ascertained and noted.

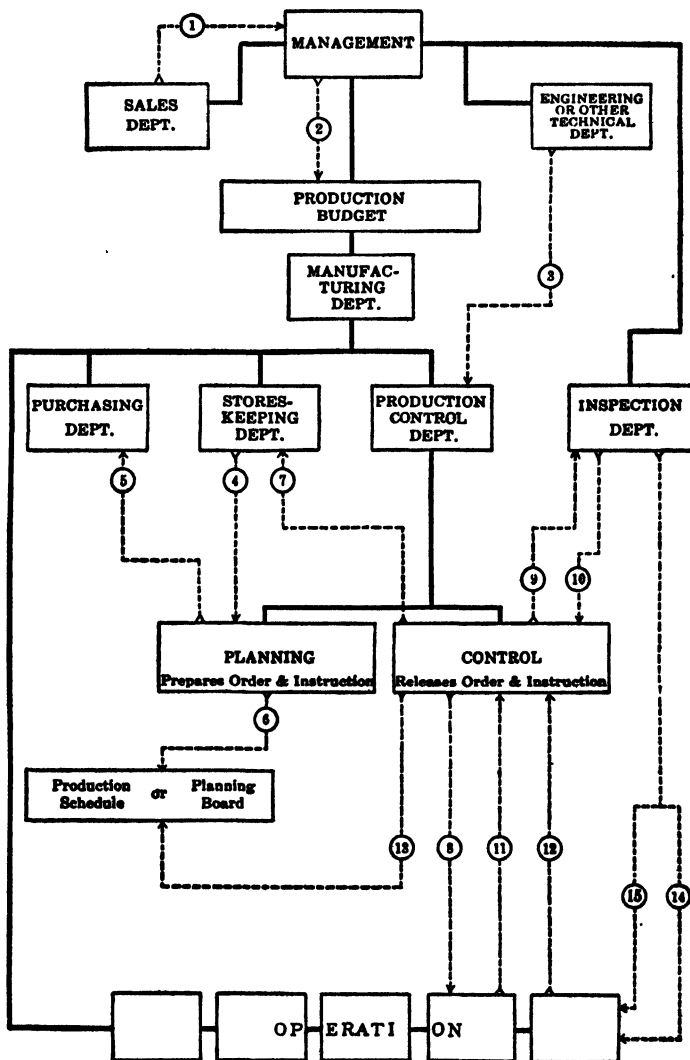



FIG. 2. Diagram of Principal Production Control Relations

6. Operations on each kind of material or part are worked out and the time required for each operation is determined and noted. Machine load charts are posted to give the dates when each operation should be begun and ended. Orders are then entered on the production schedule showing the due date of each operation. Schedules may be set up on production control boards, visible index systems, Gantt or other charts, or punched card and tabulating systems. In large plants there may be not only a central scheduling and control center but also a branch unit in each important manufacturing department.

7, 8. Dispatching for each part or operation begins on the date scheduled for beginning work on the part. Orders for (7) the issue and delivery of materials from stores are sent to the storeroom and (8) orders to do the work are sent into the operating departments.

9. Inspection orders are released upon completion of a job. After inspection—

10. Inspection reports are turned in showing the number of pieces "good" and "bad." Replacement orders are issued when it is necessary to make up shortages because of spoiled work.

11. Time records are kept on each job showing how long it has taken for completion.

12. Idle time of men and machines is reported to the production control departments.

13. Production schedule records or planning boards are posted to show steps 7, 8, 10, 11, and 12 as they occur. Progress of all work is thus kept track of and the status of any order is ascertained by looking at these postings.

14, 15. Patrolling or selective inspection often is employed to keep in touch with work as it is being done, instead of checking only completed jobs.

TECHNIQUE OF PLANNING.—The technique of production planning consists first in obtaining, in advance of actual production, as complete information as possible on all the factors which enter into the manufacturing procedure and then mapping out the course and timing of operations to bring through all the work in the most direct manner and shortest time to meet a projected completion date. The information needed, its source, and its use are indicated in the following tabulation:

1. Production material. Kind of material. Grade or quality of material. Quantity of material. Derived from analysis of product into its separate components and units.
2. Availability of material. Balances on hand and not yet apportioned or shifted to jobs. Time required for delivery where not stocked. Derived from storeskeeping and purchasing records.
3. Standard of quality for each unit. Derived from designs or specifications, or from practical experience in the class of work. Expressed as limits and tolerances in machine work.
4. Machine output or equipment capacity. Units of work per hour capable of being handled by each machine or process. Derived from analysis of machine capacity.
5. Operation method. Most efficient procedure for each operation on each unit of product, including in machine shops, determination of auxiliary equipment, tools, jigs, and fixtures. Also grouping of product units into subassemblies and assemblies. Derived from technical experience, but based on analysis of machine capacity.

6. Sequence of operations. Determining order in which operations shall be carried out on each unit. Derived from technical experience aided by accurate knowledge of machine layout and from records of previous work.
7. Operation time allowance for each operation on each unit. Derived from time and motion study, from tables embodying results of machine analysis, and from technical experience.

   Data assembled in items 5, 6, and 7 are embodied in operation sheets and instruction cards.

8. Assignment of "due dates." A date is assigned for commencement and completion of each operation on each unit of product, and for final assembly or completion of order. Derived from machine load charts and items 2, 4, 6, and 7. When assigned, these dates form the time basis of the route sheets, and of the production schedule.

Fixed factors in planning at any one period, but subject to gradual improvement, are as follows:

1. Layout of machines.
2. Conveying, handling, and transporting arrangements.
3. Storage and issue methods for material.
4. Storage and issue methods for tools and auxiliary equipment.
5. Degree to which equipment is standardized.
6. Degree to which product is standardized.
7. Degree to which operations are standardized.

Materials.—Since materials must continually come in, be processed, and go out as finished products, the factor of materials is the basic element in the flow of work. The engineering or other technical department determines—through its designs, drawings, specifications, and bills of materials—the kinds, grades, and net quantities required but analyses and calculations to find out the totals necessary to cover good work and loss, waste, and spoilage are made during the planning of production. Stores records are consulted to see whether there are sufficient unapportioned materials in the storeroom to produce each order as it comes along and, in the course of planning, the required quantities are then reserved by apportioning them on the stores records. The stores record clerk makes a request for replenishments of quantities when, for each respective material, the available amount on hand drops to a predetermined level. In the case of parts manufactured by the company from raw materials and then carried in stores as worked materials or finished parts for later assembly, the stores record clerk must see that manufacturing requisitions are issued at the proper times to replenish such items in predetermined quantities. The person who does the planning then places purchase requisitions with the purchasing department to obtain items not carried in stores. He must also find out when deliveries may be expected and cleared through inspection so that he can have processing or assembly operations scheduled in conformity with these delivery dates.

Quality of Work.—Standards of quality are set by the materials specifications established by the engineering or the technical department and by the dimensions, limits and tolerances, and finishes stated in the drawings or instructions furnished by this department. The specifications may be modified on occasion by suggestion of the shop or the purchasing department. The factory may experience difficulty in proc-

essing certain materials and ask for substitutions. The purchasing department may be unable readily to obtain the materials asked for, or may discover cheaper or more suitable substitutes. Consent of the engineering department or a ruling by management may thus modify the materials on which planning has been done. Dimensions, tolerances, or finishes may be altered upon recommendation of the shops or the inspection or quality control departments. The planner or the methods engineer in some cases may make recommendations on specifications or dimensions which may simplify or lower the cost of production. Coordination among all these departments is necessary for the most constructive planning.

Machines, Equipment, Tooling, and Methods.—Planning depends to a large extent upon the kinds, sizes, capacities, and conditions of the machines or equipment available for manufacturing. Complete analyses of such equipment and adequate records of the data thus obtained are necessary to know what work can be handled, what parts or operations may have to be subcontracted, what rates of output may be scheduled, and what quality of work can be attained. These factors are fundamental in routing, scheduling, and dispatching and are necessary for the planning of operation methods and operation sequences and the determination of operation time allowances. The methods engineer, or operations or route man, must participate in this part of the planning because he knows the plant and its possibilities and limitations. He will also be familiar with the tooling which has already been done and hence what tools, jigs, fixtures, and gages are available. If such devices are not on hand, the planner must then determine whether their costs—designing and manufacturing or purchase—and the time they may save are warranted or whether the work must be put through with the existing facilities.

Time Allowances.—The best planning can be done when data from time studies and work simplification are available to set standards of worker and machine performance. Experience on previous jobs is good only if surrounding conditions have been recorded: grade or relative skill of worker, kind of machine or equipment used, condition of equipment, tooling, nature of materials, quantities run, etc. If the proposed work is not identical but merely comparable with previous jobs, times can often be set synthetically from existing data, operation by operation or element by element.

Assignment of Due Dates.—Only after the above work has been done can the schedule for the performance of the jobs be set and dates assigned for the beginning and completion of each operation on each part, each subassembly, and the final assembly. Scheduling and dispatching make use of two kinds of records or charts, one for machine loading and one for the progress of the work. The latter would be laid out in two steps, the first showing the detailed schedule for parts and subassemblies. Since each operation must be scheduled in the light of work already assigned by date to the respective kinds of equipment or machines, and the relative urgency of respective jobs, some adjustments of the machine schedule may be necessary to bring certain orders through at the desired times. On the basis of the machine loading schedule, the second step may be taken, the layout of the summarized work

schedule for an entire order, indicating the starting time of successive operations and the over-all schedule of final assembly.

To summarize, prior to planning operations on any portion of product, these two lines of information must already be on record for reference:

1. Information as to availability of material.
2. Information as to available machine capacity.

The former information is secured through material control, the latter by machine analysis.

Collation of this information with product requirements is carried on through two channels:

1. Through product analysis definite information is obtained as to the kind and amount of material required for manufacturing unit quantities of product.
2. Through operation analysis definite information is obtained as to the time when manufacturing capacity will be in use to turn out unit quantities of product.

Preparation for production control can therefore be considered under two headings:

Affecting All Work	Affecting Specific Orders
Material control system disclosing exact status of all material at any moment.	Quantity and quality of material actually required for the order as disclosed by analysis into component parts.
Machine analysis records disclosing capacity of all machines to perform operations.	Number, sequence, and time of operations which must be performed on each component part, and each lot and assembly in the order.

Detailed Sequence of Procedures.—All the above activities are eventually performed on an order in a definite sequence practically as shown in Fig. 3. This diagram is typical for a product not fully standardized, which is often the most common occurrence. It will be noted that there are a number of forms and records to be prepared and a number of postings to be made in both the scheduling and the completion and closing out of the work. In the manufacture of a standardized article, once the procedures, forms, records and postings have been planned and provided for, the planning, scheduling, and dispatching operations become standardized and involve no radical variations until some definite change in the kind of manufacturing is introduced.

It should be noted that an operation sheet is set up for technical purposes as a standard plan of performance of an operation on a part or assembly. It states the sequence of the steps in the particular operation (milling, bench work, inspection, etc.), the departments where such work will be done, the equipment used, tooling provided, set-up times for equipment, standard time per unit for each step, and remarks on any peculiar variation or condition arising. A route sheet, on the other hand, is associated with a particular job or order. It carries an order number, the quantity on the order, sequence of operations, machines used, tooling available, date of delivery of material or beginning of work, total time for the lot on each operation, total machine time of the manufacturing cycle for the lot, date for each operation, and often provisions for entering the completion date of each operation. It is used

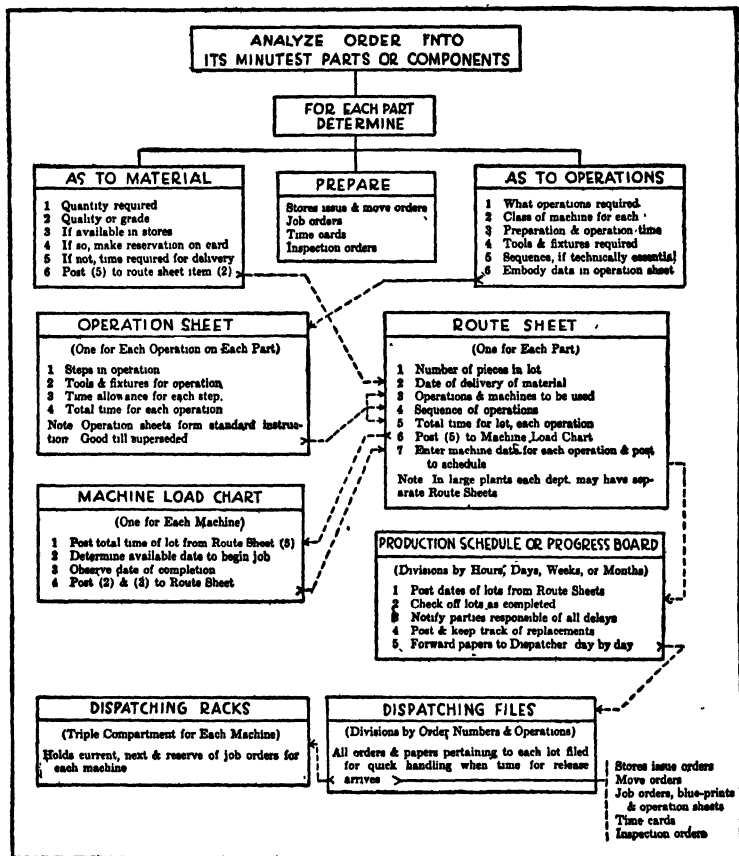



Fig. 3. Principal Items of Work on an Order Where Product Is Not Fully Standardized

for posting the work to machine load charts and to work schedules. In large plants work on a part is often completed in a single department so that the different departments may have separate route sheets.

Production Control Organization

ACTIVITIES TO BE HANDLED.—Under a comprehensive plan of organization for production planning and control, a considerable staff is needed. It should be remembered, however, that this number of per-

sons does not necessarily represent a total addition to the working force, or an increased expense which is not repaid, usually many times over, because of the relief afforded supervisors and foremen, and the greater efficiency of production which results.

Manner of Setting Up Activities.—The list given below covers all of the important production control functions:

1. Chief of production control department.
2. Planner or production man, in charge of orders. Ascertains quantities concerned in each order. Responsible for progress of orders and of deliveries. Authorizes replacements for spoiled work. Supervises preparation of purchase requisitions for materials or parts bought outside.
3. Materials control or stores record clerk. Either keeps or is in close touch with stores records. Makes reservations of material on orders being planned for production. Prepares purchase requisitions for material to be bought for replenishment of stores. Prepares or supervises preparation of stores requisitions and move orders.
4. Methods engineer. Studies drawings, bills of material, and specifications to determine methods of manufacturing, tooling, equipment changes or relayouts, etc. Prepares operation lists, tool orders, and plans for relayouts.
5. Time study and work simplification engineers. Set times on operations, and develop instruction cards.
6. Rate setters. Set wage rates on operations according to class of work and standard times established.
7. Routing man. Makes out route sheets for each part or component in order, specifying sequence of operations, machines, time allowances, and (after scheduling) due dates for each stage of the work. Supervises preparation of work orders and time tickets.
8. Order-writing clerks. Write work or operation orders, material issue slips, tool issue slips, time cards, inspection orders, move orders, purchase requisitions for items bought outside, etc.
9. Scheduler. Keeps machine load charts. Posts loads from route sheets, ascertaining dates for each operation. Keeps production schedule (Gantt charts planning board or other means). Posts progress data or jobs to schedule.
10. Dispatchers. Central dispatcher in production control office and usually also local dispatchers in shops. Keep dispatching boards or charts for their shop. File all papers to be issued in releasing orders. Frequently act as time and cost clerks. Report all completed jobs, idle machines, shortages, replacements, to production control department.

Variations According to Conditions.—Titles given in the list of positions are descriptive and may vary in wording among different companies. Because of local conditions, also, the duties may be split up under different combinations for more successful handling under the particular circumstances. Qualifications of individuals may cause variations in the assignment of duties. In other words, the functions may be consolidated or subdivided according to need. The relative amount of detail covered in each will vary according to industry and individual plant. In any case, however, the work involved under the titles given here must be provided for, whether developed to a detailed extent or carried on in a general manner because there is no necessity for more elaborate provisions.

When (as in standard repetitive manufacturing) the preliminary work of analyzing the product into its ultimate parts, listing material, making operation instruction sheets showing operations in sequence, and their necessary tools, fixtures, and time allowances, has already been done, and these data are in properly classified files, the work of the production department is confined to planning and control of routine operation on orders. Staff functions will then be fulfilled to a satisfactory degree by the following personnel, but only as long as the particular standardized manufacturing continues to be the main production carried on:

Chief of production control	Routing man
Planner or production man	Scheduler
Materials clerk	Dispatcher

The relative proportion of persons engaged specifically in production control to total number of persons on the payroll varies from about 1 in 20 to 1 in 60 or more under good systems. It is likely that the same or even higher relative proportions of executive and supervisory expense are incurred in doing the necessary work under unorganized attempts at production control. G. B. Heddendorf, of International Business Machines Corp., reports an experience of 6% to 18%, even in large plants.

REPRESENTATIVE METHODS OF ORGANIZATION.—The varied ways in which different companies set up production control activities, resulting in different forms of organization for carrying on the work, are shown in typical organization charts and manuals.

The organization for production control under less complex conditions is shown in Fig. 4. Because of the more limited nature of the work, the duties can be grouped under fewer positions and fewer persons are needed to carry on the activities.

Steps Antecedent to Production Control.—Before production control can be organized it is necessary that:

1. **Storeskeeping records** shall have been perfected and a balance-of-stores ledger card set up for each item of material entering production.
2. **Machine analysis** shall have been carried out. Hourly capacity of each productive machine on all varieties of material in current work must have been accurately determined and tabulated.
3. **Operation time study** and preparation of operation instruction sheets may either precede or be carried on simultaneously with control work. In repetitive manufacturing, the more that current practice has been reduced to instruction sheets, the less has been the hindrance to rapid production. In custom manufacturing operation study can take place only after receipt of order.

TECHNIQUE OF PRODUCTION CONTROL.—Production control rests on mechanisms by which observations of current happenings may be recorded and compared continuously with the planned program and information as to exceptions promptly handed to the persons responsible. The elements entering into successful control are:

1. Release of orders setting plans in motion at assigned time by means of dispatching. (Control of activities.)

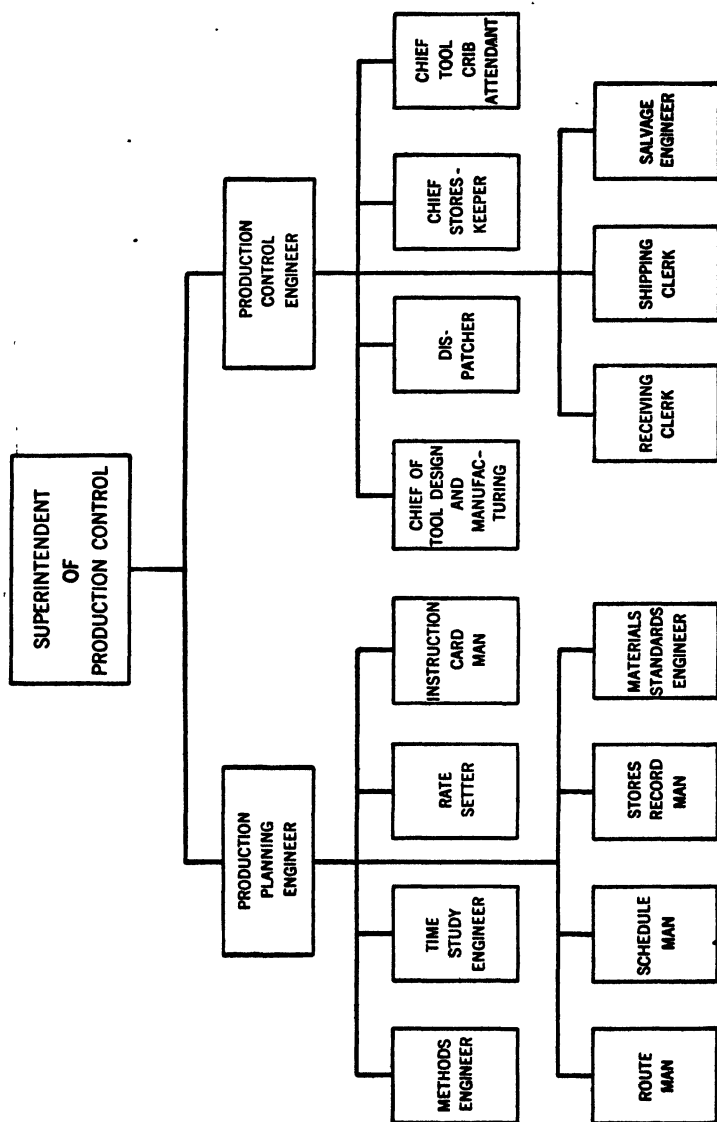



Fig. 4. Chart of Production Control Organization Showing the Functions Which It May Cover

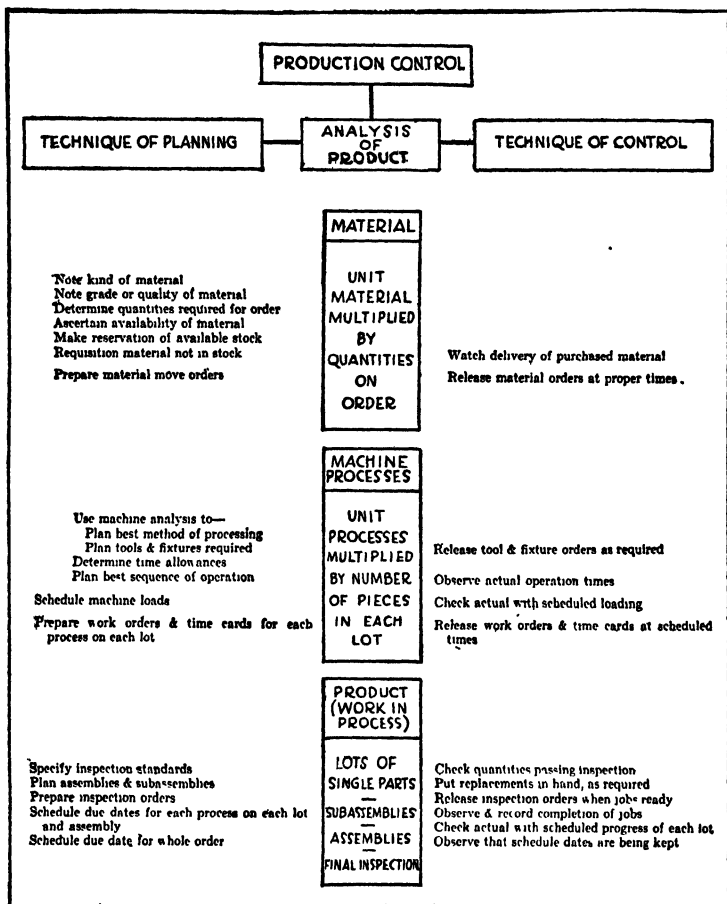



FIG. 5. Diagram of Production Control Technique

2. Observation of material, as to time of delivery, and issue to and movement within shops, as and when planned. (Control of material movement.)
3. Observation of tooling, as to design, if necessary, and manufacture or purchase, or as to issue to the shop departments from the tool cribs.
4. Observation of machine loading, as to delays or stoppages interfering with due dates of work assigned to each machine. (Control of due dates.)

5. Observation of work in process at predetermined stages to determine: (a) if the right quantity has been processed; (b) if the work done is in accordance with standard of quality. (Control of quantity and quality.)
6. Observation of the quantity of raw material and of work in process that fails to pass each stage of inspection, and issue of orders for replacing such material or work. (Control of replacements.)
7. Observation and record of time taken on each unit of work in process, and comparison with time allowance as planned. (Control of labor efficiency.)
8. Observation of progress of orders (Consolidation of items 4, 5, 6, and 7). Marking off completed work on production schedule and route sheets (Control of progress of orders).
9. Observation of movement of work by cranes, trucks, and other means of transportation and interdepartmental tracks.

Machine loading, as used in production planning and control, is defined as:

> Amount of work assigned ahead to each machine. It is sometimes wrongly called machine burden.

Cornell has pointed out that a control system should show at all times: (1) the degree to which each unit of work has been completed; (2) assigned loading of each machine; (3) earliest free date for each machine; (4) amount of orders, or quota for period, yet unfilled.

Fig. 5 summarizes the principal features of production control technique, and associates them with related planning techniques.

DIVISIONS OF PRODUCTION PLANNING AND CONTROL.—Planning and control of production operations naturally fall into four divisions:

1. Raw Materials
2. Manufacturing Technique
3. Manufacturing Facilities
4. Operating Procedure

The Control Function

DEFINITION.—Control, in production management, is the technique of setting plans in motion by the release of orders, and of observing, inspecting, and recording progress in such manner as to keep up continuous comparison between planned and actual results.

Henri Fayol defines control as:

> ". . . the ensuring that all which occurs is in accordance with the rules established and the instructions issued."

The control of production includes all devices, delegations of authority and responsibility, and procedures necessary for achievement of production objectives as defined through managerial exercise of the planning functions.

Principle of Control.—The principle of control may be stated as follows:

> **Control will be effective in proportion to the accuracy of observation of every definite step in the series of changes being wrought in material, as to quantity, quality, time, and place.**

NATURE OF THE CONTROL PROCESS.—Control of production involves three sequential managerial responsibilities as follows:

1. Initiation of operations necessary to put plans into effect, including preparation of orders and issuance to the proper persons through prescribed channels.
2. Provision of necessary means for directing the carrying out of orders, which comprises supervision.
3. Provision of necessary means for the execution of orders, which involves the performance of workers, checks, and records.

In the allocation of managerial responsibilities within the organization the first of those above mentioned falls largely within the dispatching division of the production control department.

Supervision is exercised in part by staff members in charge of production control and in part by the operating heads of the various manufacturing divisions. Execution of orders lies largely within the sphere of those heading operating departments.

Analysis of Manufacturing Technique

PRODUCTION ANALYSIS OF MATERIAL.—Analysis of product into its **ultimate parts or components** enables the following questions to be answered:

1. What parts are to be made, and how many of each go to one unit of finished product?
2. What material, and how much, enters into the manufacture of each part?
3. How many parts are combined in subassemblies?
4. What stocks, sundries, bolts, nuts, washers, etc., enter into these subassemblies and into final assembly?

Questions 1, 3, and 4 can usually be answered and listed after inspection of the drawings. Question 2 often contains factors which must be determined before the answer can be reduced to record.

Factors affecting material are: (1) quantity actually embodied in a finished part; (2) amount of scrap or waste material incurred in forming the part; (3) allowance for spoilage; (4) kind and grade of material to be used, which sometimes depends on the process selected for making the part.

The amount of material required can often be calculated from dimensions of the part. Sometimes, as in metal-stamping work, a model of the part is made, and by weighing this and calculating the proportion of scrap involved, a close estimate of the weight of metal required can be obtained. This method is employed when making bids for new work. In leather manufacture allowances for waste and scrap are more difficult, as the quality of the hide has an influence and also the skill of the cutter-out. In general, however, technical experience permits of a close approximation to the quantity of material to be ordered. An **allowance for spoilage** will be based on the experience of the average amount of spoiled parts on work of similar character.

Material Dependent on Process.—Younger (Work Routing in Production) gives an instructive illustration of the manner in which the

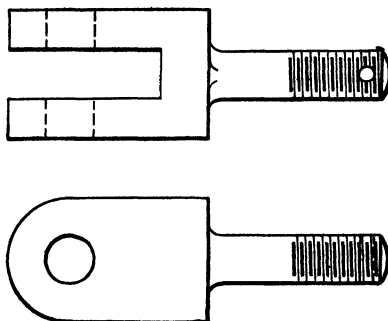



Fig. 6. Common Clevis

choice of process is often influenced by the quantity to be made, and, in turn, affects the kind of material used (Figs. 6 and 7).

Fig. 6 illustrates a common clevis. The form has been standardized, but the process of manufacture has not. The clevis can be made of malleable iron, by drop forging, upset or machine forging, cut from bar steel in an automatic lathe, or formed from cut pieces of bar steel in an ordinary machining operation. The choice of method depends largely on the quantities required. In studying the applicability of different methods, costs may be charted as in Fig. 7. Where the cost lines intersect, one form is displaced by another. This elementary but typical example illustrates the principle involved. Material cannot always be specified until after the method of processing has been settled.

When all these factors have been determined, the amount of material of a certain kind and grade required for the part can be listed. If there

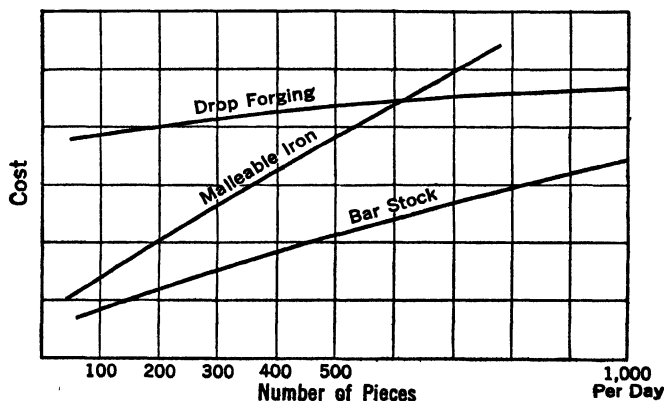



Fig. 7. Process Selection Controls—Choice of Material or Cost

is more than one identical part in a unit of assembled product, the increased number, naturally, will be taken into account. Otherwise the amount required for a single part multiplied by the number of finished units of product in the order will give the total amount of that kind and grade of material required.

Classification of Material Required.—When an exhaustive list of parts has been made, down to smallest nut, bolt, and screw called for by the drawings, and the material for these parts has been listed accordingly, an analysis is made showing:

1. Material to be taken out of stock.
2. Material to be specially purchased for the order.
3. Parts to be purchased in finished condition.

Policy as to Making or Buying Finished Parts.—It is sometimes considered more desirable to purchase certain components than to make them. The factors determining this policy are complex. They may be enumerated as:

1. **Cost.** Regular stock items can frequently be purchased more cheaply than they can be made. If the margin is narrow other considerations may enter.
2. **Time of delivery** is sometimes a strong factor. If time is an important factor in completing a customer's order, it may pay to order from outside even though no advantage in price results. Contrariwise, making the item in the plant may ensure conformity with a hurried schedule where less certain delivery could be secured from outside.
3. Parts requiring **close accuracy** to dimension may be closely supervised in the company's plant, while outside buying might result in delay due to parts not passing tests on arrival.
4. Much will depend on the **degree** to which plant capacity is **loaded.** If schedules are full with work that must be done in the plant, then the purchase outside of all possible items permits of smooth working and avoids delay. If business is slack, making the part in the plant helps to absorb factory overhead.

Purchase orders for finished parts are treated exactly as for any other material required for an order. Time of delivery must be specified and incorporated in schedule and route sheets. **Inspection of deliveries** should be made at the earliest moment, as replacement of imperfect pieces may involve considerable waiting, either to work defective pieces into shape for assembly, or to secure new pieces from the vendor.

Procedure After Listing Materials.—When the amount and grade of every kind of material required for an order have been settled, the subsequent steps are as follows:

1. Requisitions to purchasing agent are made out for (a) any material not carried in stock but specially required for the order, (b) finished parts to be purchased outside.
2. All stock material is "allotted" or "apportioned" on the stores records ledger. If, then, the reduced available quantity in any cases goes below the predetermined safe level, a purchase requisition is sent, in the usual routine, to the purchasing agent.
3. Lists of parts, with approximate time of delivery of material, if not in stock, are passed to the route clerk for orders and papers to be made out.

4. An operation study of each part to determine the method of processing, time allowance, and sequence of operations is then in order. As above stated, it may be necessary in some cases to make an operation study before the kind and quantity of material can be settled.

PRODUCTION ANALYSIS: OPERATION STUDY.—Operation study is a highly technical process. It can be entrusted only to those whose experience and technical training have made them perfectly familiar with the production problems of the class of work being done in the plant. The questions to be answered by the operation study are, in general, the following:

1. What is the **best method of making** this part?

This question sometimes involves, as explained above, the selection of a suitable material according to the process finally determined on.

2. What **definite process or processes** shall be used?

The answer to this question will usually include specifications of specific machines to be used on the job.

3. Is it desirable to specify a **fixed or definite sequence** for successive operations on the part?

It may often happen that two or more, or all, of the processes on a given part must take place, for good technical reasons, in a given order or sequence. When this is the case, the preceding and following operations should be specified on the operation sheet. They then become an overriding condition not subject to variation. The sequence desirable on account of layout of machines is discussed below.

4. What **jigs, fixtures, and tools** are necessary?

In machine-shop work the question of jigs and fixtures enters into a large proportion of jobs. Such auxiliaries may be either general or special. The first class is represented by clamps, cams, holding boxes, etc., that can be used for a variety of jobs. A drill jig relationing the position of a number of holes in a casting is an example of the second class. In other industries machines sometimes have additional attachments serving to equip the machine for special kinds of work. The common sewing machine may serve as an example. Such attachments belong to the first or general class. Specification of exactly the right kind of fixture is an important part of operation study. In the machine-shop work it is frequently necessary to design special fixtures in order (a) to be able to do the work at all, or (b) to do it in the most economical way. The actual cutting tools, e.g., lathe tools, drills, reamers, milling cutters, etc., are also frequently specified on operation sheets.

5. What **setting-up** and what **operating time allowances** are necessary in regard to each operation on each part?

All these questions are highly technical. If an operation study is undertaken by the production control division, operation study men and rate setters must be included in the staff. The chief of the division must also have a wider technical training than when operation and time study work is carried out by an engineering division and embodied in operation sheets to which the control division has simply to give effect.

Operation Study and Time Study.—An operation study prescribes methods, processes, sequences, tools, and fixtures. It assigns, tentatively, setting-up and operation times. The latter can be fully checked and permanently established only by time study carried out on actual operations. In mass production on a large scale, time study is often carried out before actual manufacture in the shops is commenced. In custom work this is hardly ever worth while. Time study when applied to such work can be profitable only if (1) disputes as to correctness of time allowances arise, or (2) if long runs of some particular item are in hand.

Operation Sequences.—The sequence in which operations shall be performed is sometimes fixed, as suggested above, by technical considerations. A casting must obviously be molded before it can be run and cooled before it can be machined. But much less obvious cases constantly occur in practice. Where very large runs, as in mass production, are in question, the **smallest gain in time per piece is worth while.**

In relatively **small-scale production,** the case is entirely different. Few concerns can afford the purchase of costly special machines for the production of a single part. For the average plant the question is one of production with such equipment as exists. The sequence of operations, under such conditions, should be as fluid as possible. When technical necessity dictates, the sequence must be fixed. But when not so dictated, it should be left optional, even though some customary or normal sequence be specified. When the question of scheduling jobs is being considered, the importance of this fluidity will be understood.

It is not infrequently stated that operations should be planned in accordance with the **layout or position of machines in shops,** to avoid unnecessary transportation of work in process. Layouts today, however, are usually carefully planned with regard to the normal run of work. Exceptional jobs may require more move work, but it would perhaps be rare that such a condition could be obviated by preplanning. It remains true, therefore, that sequences within each department should be as fluid as possible, except where technical necessity fixes their position.

When a new business is being set up or an old business overhauled, a **detailed study of the principal products** should precede the drawing up of plans for betterment of production facilities. The layout of shop departments and equipment and the relation of storerooms to incoming deliveries and to the shop departments they supply depends on the flow of work. Flow of work again has an intimate relation to the sequence of operations, first from department to department, then within each department. Such general arrangements, however, are constantly subject to variations except in those industries wherein the sequence is absolutely fixed by the nature of the productive process. Study of the product for the purpose of improving layout is a wholly different matter from daily studies of orders, and their allotment to specific machines. "A new plant," says Arthur G. Anderson, "laid out, designed, built, and equipped ready for operation by progressive managers and experienced engineers will presumably be ideal with respect to job standardization (i.e., method, time, and sequence). Where ideal conditions cannot be realized the best standards attainable can be set and maintained." Current production control must do the best possible with conditions as they already exist. Improvement of conditions, however, should be a byproduct of information accumulated by control methods.

INSTRUCTION SHEET

No. ______

PART NAME *Spur Gear (American La. Fr. Fire Eng Co)*

PART No. *2R 302*

OPERATION NAME *Turn O D. Both Sides of Face & One Side of Web*

OP. No. *5*

DEPT *11* MACH. CLASS *57* MACHS *Libby*

MADE BY *W. C.* APPROVED BY *D V.* DATE *8-1-* MAT'L *SAE 2320*

NO.	OPERATIONS	TOOLS-JIGS, ETC.	CUT SPEED R. P. M.	CUT SPEED FT./MIN.	INCHES FEED PER. REV.	INCHES FEED SETTING	TIME	
	TOOL LAY-OUT							

NO.	OPERATIONS	TOOLS-JIGS, ETC.	R. P. M.	FT./MIN.	PER. REV.	SETTING	TIME	
	SET-UP TIME							
	PROCEDURE							
1	*Chuck blank, start mach. and set stop, advance and set carriage*							97
2	*Index and advance turret. Feed*							41
3	*ROUGH O D.*	*A–¾" Sp Stellite*	23	80	.0104	96	9	30
4	*ROUGH TWO SIDES*	*B–Two ¾" Tools*	23	80				
5	*Change speed and feed*							08
6	*ROUGH WEB*	*E-Form Tool Spec.*	13	38	.008	128	1	25
7	*Back index and advance turret. Change speed and feed Throw in feed*							60
8	*FINISH O D.*	*C–¾" Tool*	60	210	.0104	96	4	30
9	*FINISH SIDES*	*D–Two ¾" Tools*	60	210	.0104	96		
10	*Change speed*							06
11	*FINISH WEB*	*F–Form Tool Spec*	8	24	.0104	96		60
12	*Stop mach and back turret*							14
13	*Back tool-post carriage and index tool-post. Advance carriage and start mach. Change speed*							56
14	*ROUND O D.*	*G–¾" Flat Tool*	23	80	H	and		35
15	*Advance tool-post*							08
16	*ROUND INSIDE of RIM*	*G*	23	67	H	and		30
17	*Back carriage and remove blank*							72
	Note—Back and index tool-post for #10 during #8 Advance carriage and set, and throw in feed for #10 during #9							
	BASE TIME for 1 piece						20	12
	Allowance 5%						1	.01
	TIME for 1 piece						21	13

FIG. 8. Instruction Sheet for a Machine Operator

Operation Sheets and Instruction Sheets.—The results of operation study are recorded in such form as to be available (1) for purposes of route sheets and scheduling; and (2) for instruction of foremen and operators. In some plants operation study determines only the processes

and approximate time allowances, details of operation being left to the foreman concerned. In other plants every step is detailed in writing and operators are expected to follow a planned method until a change is authorized. Records of the first type are called operation sheets, those of the second, instruction cards. In practice the two terms have much the same significance, and are frequently used one for the other. Both kinds, again, are frequently confused with **route sheets.** The latter, however, deal with parts and lots and, though embodying information as to processes and time allowances, are used chiefly for recording the progress of parts, operation by operation, in one department. In small plants and simple industries one sheet sometimes serves all three purposes.

Fig. 8 is a good example of an instruction sheet. Every step in the operation is set out. Tools are specified where they are to be used. Feeds and speeds are given. Time allowance for each set of motions is expressed in minutes and hundredths. Sketches of tool layout are included. Time for one piece (21.13 min.) is to be multiplied, of course, by the number of pieces in the actual lot.

Fig. 9 is an instruction sheet for wrapping asphalt shingles. In this case various manual movements connected with the packing operation are set down in detail. A standardized packing procedure is thus available for each new operator.

Procedure after operation sheets are made out:

1. As completed, sheets are filed under a symbol classification so that the sheet for any operation on any part is available for instant call.
2. If the order is already in hand, operation sheets will pass, before being filed, to the route clerk. The name of the operation and its time allowance will be entered on the route sheet for the part in question, and work tickets, tool requisitions and other papers will be made out, ready for completion with dates, as soon as the scheduling has been completed.

Simultation of Operations.—In repetitive work and in any work in which single operations last a considerable time, as in large machining work, it becomes worth while to study how far two or more operations may be performed simultaneously on the same piece, or alternatively, how two or more pieces may be passed through different phases of one operation simultaneously. This development is known as "simultation." Though hardly a matter of production control, inasmuch as it is usually a question of special equipment and layout, it may be briefly considered. Principles governing simultation are given by Alford (Laws of Management Applied to Manufacturing) as follows:

1. The minimum over-all production time for a group of operations or for the operations on an item of product, is obtained by the maximum overlapping, or simultaneous performance, of the several work units.
2. The minimum over-all production time for a group of simultaneous operations tends to approach the time of the longest work unit as its limit.

Fig. 10 shows a **comparative operation sheet** embodying the results of the progressive simultation study. At the top left-hand are four graphs showing the increasing proportion of actual productive to total operation time as simultation increases.

INSTRUCTION SHEET FOR OPERATION — SYMBOL NO. 10

DRAWING NO.	MACHINE NO. LATITE 11-12-13-14	ORDER NUMBER	NO. OF SHEETS 2 SHEET NO. 1
MATERIAL: SLATED	PIECES IN LOT: 16" LATITE	PIECES IN LOT: 82/SQ.	TIME FOR LOT	BONUS: SHEET OF 12-30 —

DESCRIPTION OF OPERATION: STACKING 16" X 16" LATITE SHINGLES INTO WRAPPER HELD IN FIXTURE OF PACKING CONVEYER. OPERATIONS PERFORMED BY MAN AT POSITION R.

PHOTO NUMBER 13

LINE NO.	DETAILED INSTRUCTIONS	FEED	SPEED	SUB OPERATION TIME PER PIECE	TIME FOR ENTIRE LOT	CONTINUOUS OR RUNNING TIME
1	A--FIRST AND EVERY ODD NUMBERED SHINGLE					
2	IN ORDER OF STACKING. (SEE SKETCH ABOVE)					
3						
4	PRESS DOWN AT POINT "A" OF SHIN-					
5	GLE ON DISCHARGE TABLE WITH THE LEFT					
6	HAND, PALM DOWNWARD, AND SLIDE IT TOWARD					
7	THE WRAPPER. IN THE MEANTIME ALLOW IT TO					
8	TURN SLIGHTLY IN A COUNTER CLOCKWISE					
9	DIRECTION ABOUT ITS CENTER.					
10						
11	RELEASE PRESSURE WITH THE LEFT					
12	HAND AND GRASP THE SHINGLE AT B WITH					
13	THE RIGHT HAND, PALM UPWARD, FINGERS					
14	UNDERNEATH AND THUMB ON TOP. MOVE					
15	LEFT HAND TOWARDS THE NEXT SHINGLE ON					
16	DISCHARGE PLATE.					
17						
18	MOVE SHINGLE INTO WRAPPER WITH					
19	THE RIGHT HAND, SWINGING IT COUNTER-					
20	CLOCKWISE SO THAT THE SLATED SIDE WILL					
21	BE UNDERNEATH.					
22						
23	RELEASE THE SHINGLE IN THE WRAP-					
24	PER WHEN THE CORNER "1" IS AT "E" AND					
25	THE CORNER "4" IS AT F.					
26						
27	B-- SECOND AND EVERY EVEN NUMBERED					
28	SHINGLE IN THE ORDER OF STACKING.					
29						
30	PRESS DOWN ON CENTER OF SHINGLE					
31	WITH LEFT HAND, PALM DOWNWARD. SLIDE IT					
32	TOWARDS THE WRAPPER UNTIL CORNER 1					
33	EXTENDS OVER THE EDGE OF THE DISCHARGE					
34	PLATE.					
35						
36	GRASP THE EAR OF THE SHINGLE WITH					
37	THE RIGHT HAND, PALM UPWARD, FINGERS					

	MONTH	DAY	YEAR	APPROVED
EFFECTIVE				JAP
JHW	7	9	—	BY SFO 8/26/ —

Fig. 9. Instruction Sheet for a Packing Operation

MACHINE

ENGINE LATHE Single operations one at a time	Prod Min	Prod Sec	Non-Prod Min	Non-Prod Sec	Total Min	Total Sec
Chuck				12		12
Drill		25		2		27
Bore		24		2		26
Ream		12		2		14
Press on arbor				12		12
Mount between centers				12		12
Machine outside diameter	3	24		30	3	54
Machine one side	3	24		45	4	9
Machine other side	3	24		45	4	9
Totals	11	13	2	42	13	55

TURRET LATHE Single operations plus cross slide	Prod Min	Prod Sec	Non-Prod Min	Non-Prod Sec	Total Min	Total Sec
Chuck				12		12
Face top & outside diam.	3	24		2	3	26
Drill hole		25		2		27
True hole		24		2		26
Ream hole		12		2		14
Undercut bore & undercut rim	1	43		2	1	45
Finish straddle face rim & hub	1	00		2	1	02
Totals	7	8		24	7	32

SINGLE SPINDLE CHUCKER Group Tools	Prod Min	Prod Sec	Non-Prod Min	Non-Prod Sec	Total Min	Total Sec
Chuck				12		12
Bore hole & turn outside diam.	3	24		2	3	26
True bore & straddle cut rim	1	43		2	1	45
Ream hole		12		2		14
Straddle hub		34		2		36
Totals	5	53		20	6	13

MULT-AU-MATIC	Prod Min	Prod Sec	Non-Prod Min	Non-Prod Sec	Total Min	Total Sec
Chuck	1	43		8	1	51
Rough turn upper half & chamfer hole	1	43		8	1	51
Rough turn lower half & core drill	1	43		8	1	51
Straddle face hub & face rim on both sides	1	43		8	1	51
Finish straddle face hub & fin. face rim	1	00		8	1	08
True bore, ream hole & finish turn	1	43		8	1	51
Totals					1	51

FIG. 10. Comparison of Operations on Single-Purpose Machines and on Automatics

Simultation in Relation to Operating Efficiency.—Operations having to be performed in the same time cannot always be performed at maximum efficiency. Blanchard has pointed out that "the secondary or tertiary operations—performed simultaneously with the primary operation by which the rate of performance is set—may be permitted to lag in certain points of efficiency, provided only that the work be accomplished within the time limit set by the primary operation." In other words, the problem is to obtain a net advantage on the whole series, even though particular operations might be more efficient if conducted singly.

Another example of the principle of simultation is afforded by a baking oven through which the product is slowly moved by a conveyor. Such an operation may be adjusted to any rate of flow within reasonable limits, and as long as the material is just sufficiently long in the oven to be completely baked, dried, or ripened, the required results are accomplished. At any one time individual pieces may be at all stages of drying, but the net cost is far below that of small batches handled in individual ovens.

Simultation in **assembly work** is now common practice. Assembly operations are subdivided into units capable of being handled by single operators. A belt or rotary table carries the product forward, each operator performing his unit task simultaneously with all others. Thus, in drug and similar industries, bottles are loaded on to a conveyor, filled, labeled, sealed, and then removed from the table, the five successive operations being in simultation. A further stage is reached when some or all of the steps are performed automatically. In the above particular instance the latter stage has already been reached.

Simultaneous production can also be effected in the case of lots containing a large number of pieces, without special tools or devices. As soon as one day's product is free from machine A, it is passed to machine B for the next process. A and B are thus both working on the same job at the same time, though on different individual pieces of it. This procedure does not economize labor or machine time, but it does speed the passage of the job through the shops. It may be described as "overlapping" or "telescoping" rather than "simultaneous" production.

From the control viewpoint, simultation on the same unit of product simply shortens the time during which the machine is occupied by the job. When the process is applied to different units, control boards and route sheets must be so arranged as to permit grouping of these units for simultaneous processing.

ANALYSIS TO DETERMINE ECONOMIC LOT SIZES.—In repetitive manufacture where the annual output is made up of long runs of identical pieces, the problem of **maximum and minimum lot sizes** is one requiring attention. It is of far more importance from an economic standpoint than is usually realized. Concisely stated, it may be said that a sufficient number of pieces must be run in each batch to offset the cost of planning, ordering, tooling, moving, and making ready the work and the machine, but not so many as to incur avoidable carrying charges on idle finished parts. There is obviously a point at which these two influences on cost will balance each other. Given certain conditions the problem becomes solvable by mathematical analysis.

Approximation by Tabulated Instances.—It can also be attacked by the method of tabulated instances. Younger (Work Routing in Production) gives an example from which the following illustration is condensed:

Yearly production capacity of plant..............	125,000 pieces
Actual demand	20,000 "
Cost of setting up and getting ready for lot........	$605
Cost of raw material, per piece....................	$ 2
Cost of finished part............................	$ 10
Labor cost per piece, including overhead but not material burden—taken as factor T	

If all 20,000 pieces are made in one batch at the beginning of the period, the total cost is:

$$\$605 + 20{,}000\,T + \text{Interest on material for remainder of year}$$

but as the product will be sold or utilized continuously during the year, only one-half the interest item is taken. This interest amounts to $1,008. Interest on value added by processing must also be charged. This additional item (one-half as before) is found to be $4,032.

Therefore, when 20,000 pieces are made all at once, the total cost is:

$$\$605 + 20{,}000\,T + \$1{,}008 + \$4{,}032 = \$5{,}645 + 20{,}000\,T$$

Next, consider the case where two lots of 10,000 pieces each are put through. Charges on material and on added value are only half as great, and only half the quantity is kept in average storage, but setting-up cost is doubled. Hence:

$$2 \times \$605 + 20{,}000\,T + \$504 + \$2{,}086 = \$3{,}730 + 20{,}000\,T$$

Similarly, it may be found that cost of putting through:

3 lots is $\$3{,}462 + 20{,}000\,T$
4 lots is $\$3{,}680 + 20{,}000\,T$
5 lots is $\$4{,}033 + 20{,}000\,T$
6 lots is $\$4{,}470 + 20{,}000\,T$

Deducting the factor 20,000 T which is common to all, the above results are plotted on a curve (Fig. 11) from which it will be seen that three

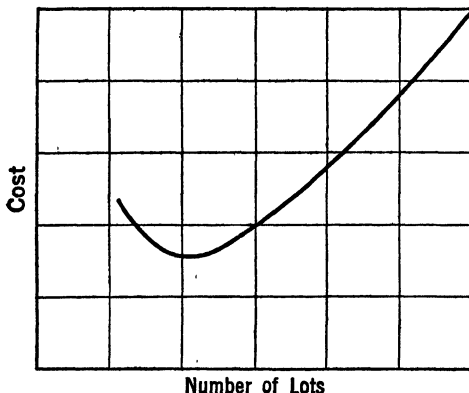



FIG. 11. Plotted Curve Showing Most Economic Lot Size

lots per year give the most economical production. A saving of $2,183 is made by putting through three lots instead of one, and $1,008 by putting through three lots instead of six.

If total carrying charges were included instead of merely interest, other relationships would be obtained.

Formulas.—Several authorities have developed approximate formulas for calculating economic lot sizes. While exact mathematical determina-

tion is impossible because of the empirical or necessarily assumed nature of some factors, the formulas do include the factors that must be taken into account and insert them in their respective relationship. Thus the formulas become useful guides, but all must be employed with judgment.

Formula of Camp.—Camp was the first to present (1922) a general formula to determine the production order quantity, such that the total cost per unit for setting up plus interest on stores investment would be a minimum. Numerous studies of this kind were subsequently made. Camp's formula is:

Let S = Set-up cost per order in dollars
C = Cost per piece (labor, materials, operating expense, or a portion thereof) in dollars
R = Rate of consumption per year in pieces
I = Interest on investment, dollars per piece (Interest rate × C)
Q = Order quantity

The general formula then is:

$$Q = \sqrt{\frac{2RS}{I}}$$

This formula is somewhat unwieldy for the reason that the quantity under the square root sign is very large. If the interest rate is standardized for all cases, a formula results that can be plotted into curves to be used for calculating. Assuming 10% is fixed upon as to the rate to cover interest on the investment in stock and bin-space rental, then:

$$Q = \sqrt{\frac{20RS}{C}}$$

$$\text{Let } K = \sqrt{\frac{20S}{C}} \tag{1}$$

$$\text{and } Q = K\sqrt{R} \tag{2}$$

The last two formulas plot into useful curves. Knowing the set-up cost and cost per piece, the value of K may be read from the chart plotted from formula (1). Introducing the value of K thus found into the chart plotted from formula (2), and knowing the yearly consumption, the value of Q may be readily found with sufficient accuracy for all practical purposes.

Studies by Raymond.—At the request of the American Society of Mechanical Engineers, Raymond (Trans. A.S.M.E., MAN-50-10) undertook to consolidate previous studies on the mathematical treatment of the problem. Omitting the steps by which the formula is built up, the following example of its practical application will show the factors taken into account:

Suppose a screw-machine job is to be done; with the following as data, what will be most economical lot quantity?

P = 2,000 pieces per day, rate of production
Y_a = 1 500 pieces per day, average sales demand

F = $D + G + O + T + S$ = cost of drawing + planning + ordering + tooling + machine set-up = \$100 + \$25 + \$10 + \$250 + \$30 = \$415

c' = Unit of manufacturing cost, $m + l + o$ = material + labor + overhead = \$.005 + \$.02 + \$.015 = \$.04

i = Interest earned on capital invested = 25% for 300 days = \$.25/300 per dollar per day

k = ½ = stock coefficient

n = 10 = number of batches

c'' = Average unit value of each batch = $m + ½(l + o)$ = \$.005 + ½ (\$.02 + \$.015) = \$.0225

k_p = c''/c' = \$.0225/\$.04 = \$.563

v = \$.10 per cu. ft. per year, value of storage space per unit = \$.10/300 per day

B = Cu. ft. occupied per unit (assume 100 pieces go in a 1 ft. x 6 in. x 6 in. box) = (1 × ½ × ½)/100 = .25/100 cu. ft.

a' = Time factor for batch production = $(1 + a_1 n - a_1)$. Let $a_1 = t_1/t' = .20$, where t' = process time first batch and t_1 = process time first operation for one batch. Then a' = (1 + .20 × 10 − .20) = 2.80

$$Q = \sqrt{\frac{FPY_a}{c'i\left[kP - Y_a\left(\frac{1-\frac{1}{n}}{2}\right)\right] + c'iY_a\frac{k_p}{a'} + vB\left[P - Y_a\left(1-\frac{1}{n}\right)\right]}}$$

$$= \sqrt{\frac{415 \times 2{,}000 \times 1{,}500}{.04 \times \frac{.25}{300}\left[\frac{2{,}000}{2} - 1{,}500\left(\frac{1-\frac{1}{10}}{2}\right)\right] + .04 \times \frac{.25}{300} \times 1{,}500 \times \frac{.563}{2.8} + \frac{.10}{300} \times \frac{.25}{100}\left[2{,}000 - 1{,}500\left(1-\frac{1}{10}\right)\right]}}$$

$$= \sqrt{\frac{1{,}245{,}000{,}000 \times 100}{.0033\,[325] + .0033\,[302] + .000083\,[650]}}$$

$$= \sqrt{58{,}650{,}000{,}000} = 242{,}300 \text{ pieces, economic production lot}$$

$$\text{or } \frac{242{,}300}{2{,}000} = 121.2 \text{ days' production}$$

Use 122 days' production.

Though giving exact computations, this formula is somewhat complex for ordinary purposes.

Simple Formula of Lehoczky.—Lehoczky has developed a simpler formula giving sufficiently accurate results for all practical purposes, particularly where operations are not on the largest scale. The factors and symbols of the Lehoczky formula are as follows:

X = Number of lots to be produced per year
M = Interest on raw material if purchased once a year

$L =$ Set-up charge

$J = \frac{\text{Output}}{\text{Capacity}}$

$S = \frac{\text{Cost of finished product}}{\text{Cost of raw material}}$

The formula, using these symbols, is:

$$X = \sqrt{\frac{M}{L}\left[\frac{S + J - SJ}{2}\right]} \qquad (3)$$

Using the quantities given in the example under the Raymond formula above, the Lehoczky formula gives results as follows:

$$X = \sqrt{\frac{.06 \times 1{,}500 \times 300 \times .005}{30}\left[\frac{\frac{.04}{.005} + \frac{1{,}500}{2{,}000} - \frac{.04}{.005} \times \frac{1{,}500}{2{,}000}}{2}\right]}$$

$X = 2.48$ lots per year, or $\frac{300}{2.48} = 121$ days' production

The Raymond formula gives 122 days as the time of economic production. The Lehoczky formula gives 121 days. In practical terms, both these results would be rated as five months' production and schedules prepared on that basis.

Simplified Method of Norton.—Norton (M.E., vol. 55) has developed another simplification by omitting factors which are relatively unimportant, and retaining all those that materially affect the problem. His symbols are:

Q = The lot size (pieces per lot)
Q_e = The economic lot size (pieces per lot)
S = Total preparation cost per lot (dollars), including cost of preparing manufacturing orders, cost of setting up machines, and any other similar costs which are independent of the number of pieces in the lot
P = Pieces made per day
U = Pieces used per day
N = Days worked per year
C = Material, direct labor and overhead per piece (dollars)
A = Cost of storing one piece for one year (dollars)
B = Taxes, insurance, etc., per cent per year on inventory
I = Desired return on capital, per cent per year
V = Total amount charged against each piece:
(a) For preparation costs, including costs in production control department as well as cost of machine set-ups
(b) For material, direct labor, and factory overhead
(c) For storage charges, including desired return on capital

For the sake of simplicity neglect the preparation cost per piece in figuring the capital tied up in inventory. Also assume that the total amount per piece for material, direct labor, and factory overhead, C, will be charged from the time that production begins. Errors due to these assumptions will be minor in most cases, and it will be noted from all the above formulas that, as these cost factors appear, respectively, in numerator and denominator in each formula, they tend to cancel each other. After the lot size has been determined under these assumptions,

it is a simple matter to determine the relationship between the various unit costs for the lot size that has been determined and further to adjust the lot size, although such adjustment will rarely be necessary.

It is customary in analyses of this sort to assume that the consumption rate will be uniform, in which case the average time that any piece is tied up in production and storage will be $\frac{Q}{2U}$ days, or $\frac{Q}{2NU}$ years. If the demand is markedly seasonal and the amount of capital tied up in inventory is considerable, it may be desirable to manufacture in lots of different sizes during different seasons. The proper lot size for each season may be determined simply by using the proper consumption rate.

$$\text{(4)} \qquad \text{Unit cost for taxes, insurance, etc.} = \frac{BCQ}{2NU}$$

$$\text{(5)} \qquad \text{Unit charge for return on capital} = \frac{ICQ}{2NU}$$

$$\text{(6)} \qquad \text{Unit cost of rental of storage space} = \frac{A\left(1 - \frac{U}{P}\right)Q}{NU}$$

It is assumed that storage space must be provided for the maximum number to be placed in storage from lot Q. The fraction of the lot that goes into storage is $\frac{P-U}{P}$. Where P is very large in comparison with U, the number for which storage must be provided is practically Q.

The total charges per piece, incident to storage, are the sum of (4), (5), and (6), and may be written

$$\text{(7)} \qquad \left[\frac{(B+I)C + 2A\left(1 - \frac{U}{P}\right)}{2NU}\right]Q$$

As all of the quantities within the brackets are constants, quantity (7) may be simplified to read KQ.

The total charge against each piece will be

$$\text{(8)} \qquad V = \frac{S}{Q} + C + KQ$$

$$\text{Then, } \frac{dV}{dQ} = -\frac{S}{Q^2} + 0 + K$$

V will be a minimum when $\frac{dV}{dQ} = 0$, and therefore the lot size for minimum V may be found from the formula:

$$\text{(9)} \qquad Q_e = \sqrt{\frac{S}{K}}$$

This formula is quite similar in appearance to many other economic lot-size formulas that have been developed, but includes important factors that are ordinarily omitted such as desired return on invested capital in place of simple interest. Formula (9) may be written:

$$\text{(10)} \qquad \frac{S}{Q_e} = KQ_e$$

This shows that, for the economic lot size, the unit preparation charges are equal to the unit charges incident to storage. This relationship is useful in cases where it is desired to solve a problem of this sort by cut-and-try or graphical methods.

While the approximately constant unit cost of material, direct labor, and factory overhead, C, does not appear directly in the final formula, it does affect the economic lot size because K is a function of C.

It should be noted carefully that V does not represent the manufacturing cost per piece, because I is not simple interest on invested capital. Factor I is the total return on invested capital that is necessary in order that this particular capital may earn its share of the profits of the business. The usual formula, which merely charges the capital invested in inventory with simple interest, may determine correctly the size of lot for minimum manufacturing cost, but it does not consider the advantage which may be obtained by turning over capital more rapidly, even though the actual manufacturing cost may be somewhat higher on account of the larger unit preparation cost with smaller than minimum-cost lot size.

An example shows how the formula is used, and the difference in the result obtained when the desired return on capital is used instead of simple interest. Assume the following values:

$S = \$10.00$ $\quad$ $C = \$.10$
$P = 1{,}000$ $\quad$ $A = \$.001$
$U = 100$ $\quad$ $B = 3\%$
$N = 300$ $\quad$ $I = 20\%$

Substituting in (7):

$$K = \left[\frac{(.03 + .20) \times .1 + 2(.001)\left(1 - \frac{100}{1{,}000}\right)}{2(300)(100)}\right]$$

$$K = \$.41 \times 10^{-6}$$

$$\text{and } Q_e = \sqrt{\frac{10}{.41 \times 10^{-6}}} = 4{,}940 \text{ pieces}$$

If, however, a simple interest rate of 6% were used in place of I, K would be $\$.16 \times 10^{-6}$, and Q_e would be 7,900 pieces. Based on the usual method of figuring costs, this latter value would be the lot size for minimum cost, but it would be undesirable, as it would not give a sufficient rate of turnover of capital invested in inventory.

Tabular Method for Calculating Economic Lots.—Under this method of analysis the tabulation is made of variable items of cost for several assumed numbers of lots to be manufactured in a year. The lowest cost indicates the economic annual number of lots, which, divided into the annual consumption, gives the number of pieces in a lot that can be calculated.

The following example shows this method. Assume these data:

Preparation cost	= \$15
Storage charges per piece per year	= \$.001
Manufacturing cost per piece	= \$.25
Desired annual return on capital	= 10%
Manufacturing capacity per year	= 1,000,000
Demand for pieces per year	= 960,000

Further data for the computation are arranged in Fig. 12. The lots studied range from one per year to seven per year; the corresponding sizes of the lots range from 960,000 to 137,000. This table also gives maximum inventory in pieces, computed from a production per week of 20,000 pieces, and a demand per week of 19,200 pieces. The difference, 800 pieces, is carried to inventory for each of 48 weeks, the time required to make 960,000 pieces when one lot is made per year, giving a maximum inventory of 38,400 pieces. Investment in inventory is the number of pieces multiplied by the manufacturing cost per piece.

Number of lots per year	1	2	3	4	5	6	7
Number of pieces per lot	960,000	480,000	320,000	240,000	192,000	160,000	137,000
Maximum inventory in pieces	38,400	19,200	12,800	9,600	7,680	6,400	5,600
Maximum investment in inventory	$9,600	$4,800	$3,200	$2,400	$1,920	$1,600	$1,400

Fig. 12. Data for Computation of Manufacturing Lot Size

Fig. 13 gives **costs that vary with the size of the manufacturing lot,** these being preparation and storage costs, and interest on investment in inventory. Examination shows that the lowest annual cost for the sum of these three charges is when six lots are made per year. However, there is no practical difference in costs for five, six, and seven lots per year, showing that there is a considerable range for the economic number of pieces per lot.

Number of lots per year	1	2	3	4	5	6	7
Preparation cost per year, $15 × number of lots	$ 15.00	$ 30.00	$ 45.00	$ 60.00	$ 75.00	$ 90 00	$105.00
Storage cost per year, one-half the maximum number in inventory	19.20	9.60	6.40	4.80	3.80	3.20	2.80
Interest charge per year, one-half investment in inventory × .10	480 00	240 00	160 00	120 00	96.00	80.00	70.00
	$514.20	$279.60	$211.40	$184.80	$174.80	$173.20	$177.80

Fig. 13. Cost Comparisons for Manufacturing Lots of Various Sizes

The total costs given at the bottom of Fig. 13 plot into an **economy curve** similar to that of Fig. 11

Analysis of Machine Capacity

ANALYSIS OF MACHINE CAPACITY.—Production consists, in general, of operations by machines on material. When the necessary information as to material and methods of manufacture has been developed, the next step is to acquire equally accurate information as to the capacity of the machines to operate on the material. This information is secured by what is known as machine analysis.

Machine analysis may be a quite simple or a very difficult and complex study according to circumstances.

PRINCIPLE OF MACHINE ANALYSIS.—The object of machine analysis, like that of materials control, is to answer definite questions. In considering a machine, the first question likely to arise is:

1. How long will this machine take to perform its operation on a unit quantity of material?

This question can be answered either (a) by **actual experiment and trial,** or (b) by reference to **records of past performance.** Though this appears a simple enough procedure, it is not infrequently complicated by the fact that speed of operation varies (a) according to nature of material, (b) according to the degree of finish or accuracy required.

In machine work operation the speed varies according as hard steel, cast iron, brass, copper, aluminum, etc., are being worked on. The condition of the castings may cause wide variations in possible operating time. If coarse work is being done, quicker work may be expected than when fine tolerances are being aimed at. In working near the limit of capacity of a machine, insufficient power may be available, or the awkward character of the job may prevent power being applied in the right amount. In textile manufacture operation speeds vary with the nature of yarn or fabric. In many paper industries the particular material being worked on is a controlling factor in operating speed. In fabric dyeing a jig will vary in output from 300 to 1,800 yards per run depending on the weight and substance of the fabric. On the other hand, many industries working on uniform material can answer the above question almost offhand.

Preparation, "Make-Ready," or "Setting Up."—Actual time consumed on a job is made up of two factors in all machine tool work, and in many other cases. It takes time to get the equipment ready to do the job. This is called "setting up" or, in the printing trade, "make-ready" time. When it exists it is a very variable factor, frequently difficult of predetermination, since it varies with the nature of the job itself.

In the "make-ready" of a large press for printing a three-color job from fine blocks, long and tedious work is sometimes necessary, the amount of which is wholly unexpected, owing to some slight peculiarity or inadaptation of blocks, speed, pressure, ink, or paper. Once these are mutually adjusted the operation proceeds at an expected speed, but if the run is not a long one, the cost of the job may be affected unfavorably. In setting up machine tools, proper holding of work is frequently a problem, only to be solved by the design of a special fixture or jig. Cutting speeds and feeds have to be determined and much preliminary

work done before the job is actually set going. In more fortunate industries no such preparation is necessary. Material is placed in a hopper or fed into grips and drawn into the machine without further attention. Where preparation time is considerable, the question of the economic size of lots to be worked on at one setting becomes important.

In **machine tool** and similar work, question 1 must be elaborated or extended so as to read:

1a. How long does it take to make this machine ready for a new job?

1b. How long does this machine take to perform the actual operation on a unit quantity of material, once it has been set up?

From what has already been said it will be seen that the first of these new questions can be answered only in an average way. We may say that an average job takes *n* minutes to get set up. But when it comes to the consideration of a specific job, this factor requires careful scrutiny to make sure that there are no exceptional inherent difficulties. In many cases only experiment will disclose the proper time assignable. This phase of the problem belongs to the subject of operation study inasmuch as it is individual to specific jobs.

Question 1b is capable of fairly exact predetermination. Either by careful study or from accurate records the operation time of the machine can be determined for each variety of material usually met with in the plant.

Total Capacity in Terms of Time.—The second question in machine analysis is:

2. How many units of each variety of material can be processed on this machine per day, week, or month?

Aggregation of the number of units processible by similar machines gives the total plant capacity in units of product for one process. When all processes have been analyzed and tabulated, a third question can be answered:

3. What is the maximum plant capacity per day for each process on each variety of material?

UNITS OF CAPACITY.—Units of product in which capacity may be expressed vary necessarily according to industry. In textile and other fabric industries poundage of yarn and yardage of fabric are usual. In foundries a tonnage basis may be expected. In machine shops the problem is, in general, vastly more difficult. Machine analysis in relation to machine tools, e.g., lathes, implies determination of interaction of several factors: power, spindle speed and torque, maximum chip area, length of piece that can be operated on, swing over, and feeds available (Hallock, Production Planning). All these variables must be taken into account before actual performance can be ascertained. Output capacity of machine tools can therefore not be stated in general terms, except in cases where long runs of identical pieces enable such output to be stated in dozens or hundreds per hour. It can, however, be reduced to tables by the aid of which any particular problem can be solved.

Machine analysis therefore has **two important objectives:** (1) To determine approximate maximum capacity of each process and hence of all processes, and the plant as a whole. This determination can be made

only when output can be expressed in definite terms of number, weight, yardage, etc. (2) In machine shops and industries where several factors enter into machine capacity, analysis provides a basis for calculating the **time of operation on specific jobs.** The calculation is usually effected by embodying the results of machine analysis in tabular or monographic form. When the time taken by the job is determined, both as to set-up and operation, the period during which the machines will be occupied by such jobs will be proportional to the size of the lots going through. Machine loading for all planned jobs is then easily determined. The **amount of work ahead** of each machine, expressed in working hours, becomes a known quantity.

Balanced Capacity.—Machine analysis also enables the relative capacity of each process in the general flow of work to be exhibited. It is generally recognized that "bottlenecks" are the most serious hindrance to economical production. When the output of each process for each variety of material has been charted or tabulated, flow sheets can be drawn which will show at once if an excess of machine capacity, or insufficient capacity, exists at any particular point or points.

MACHINE LOADING.—Every job allotted to a machine decreases its capacity for additional work in a given period. It is therefore essential to know how far the work in hand will occupy the machines, and, as each new order comes in, what time it will require for processing in each operation to be performed on it. Machine analysis has been indicated as the procedure by which the productive capacity of machines is ascertained. In considering machine loading, i.e., "load" or quantity of work assigned to each machine, two controlling conditions are found, as follows:

1. Where capacity can be expressed in terms of product output—pounds, numbers, yardage, etc., per hour.
2. Where it can be expressed only in hours of work.

In the first case operation study is not required. Dividing the number, weight, or yardage, in the lot on order by the hourly capacity of the machine gives the "load." Different grades of material may take different speeds, but for a given kind of material the time of processing is easily ascertained. Thus, a printing press or a dyeing machine has a known output per hour, though depending on particular paper or fabric and other factors in a particular lot.

In the second case, which includes practically all machine tools not specialized for particular work, operation study must first determine a time allowance of the unit of product to be processed. The machine load for a specific order can then be ascertained by multiplying the unit time allowance by the number of pieces in the lot on order. In most machine-tool work an additional "setting-up" time allowance must be made. Machine loading control has **two main objectives:** (1) to keep machines continuously at work; (2) so to assign dates for processing each unit of an order that production in the shortest possible time results. A byproduct of this control is observation of the degree to which overload or underload occurs on particular machines or classes of machine.

Overload may be temporary or persistent. If temporary, relief can be had (1) by working overtime, or (2) by rerouting jobs to other ma-

chines, if available. Persistent overload must be met by additional equipment, alteration of the method of production, procurement by purchase, or subcontracting.

Underload may arise from insufficient work. In custom manufacturing underload may easily occur, and for this reason a certain amount of stock manufacturing is a good accompaniment of custom work. Underload of certain departments may also arise from poor planning, in which case the remedy is to plan more closely.

Mechanism of Machine Loading Control.—Some mechanism must be arranged to keep track of machine loading, and to permit of free dates being found as new orders come along. The mechanism may be either on the ledger or graphic principle. The particular form is a matter of choice. Graphic methods, if well designed, appear to be more flexible.

All **graphic methods** of control depend on the idea of representing time by linear measurement. This plan applies to Gantt charts and control boards whether for loading or scheduling. A simple and effective device (Fig. 14) was in use in an English plant many years ago, controlling the loading of a foundry in connection with a large machine

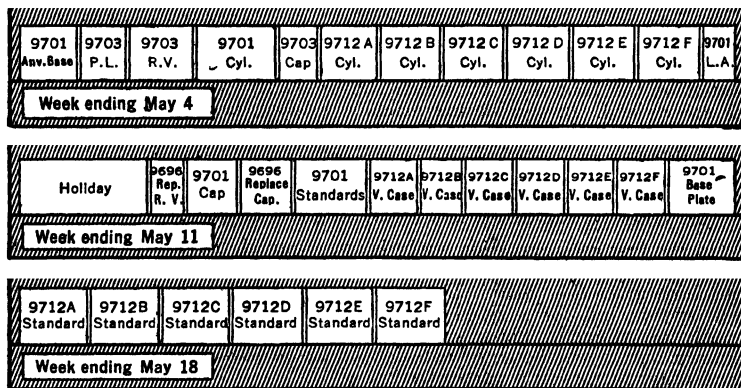



FIG. 14. Device Controlling the Loading of a Foundry to Capacity

Each horizontal bar is to scale to represent one week's output of large castings. Card widths are to same scale. Sequence of cards alterable as desired.

works. Tonnage output of the foundry was known for (1) large, (2) small work. A separate frame was used for each class. Each horizontal bar represented the output for one week at 3 tons per inch (on original device). Cards were cut so that their width indicated the weight of the casting. Each card was one unit of an order—the order number and the name of the casting appearing on the face of the card. A glance at the frame shows **how many weeks ahead** the foundry was loaded, and the earliest free date. Cards, being movable, could be changed in sequence, orders which developed urgency being moved up for an earlier

DEPARTMENT M-4 Turret Lathes Shop Planning Schedule for Week Starting May 4

Machine	Mach No
12" P & W	D-05
12" "	D-06
14" P & W	D-07
14" "	D-08
10" Hendey	D-10
10" "	D-12
12" W & S	D-22
12" "	D-23
12" "	D-24
6" J & L	D-31
6" "	D-32
6" B & S	D-48

Monday 1st 2nd · Tuesday 1st 2nd · Wednesday 1st 2nd · Thursday 1st 2nd · Friday 1st 2nd · Saturday 1st 2nd

PROGRESS CHART

FIG. 15. Gantt Chart for Machine Loading
(Boyan, Handbook of War Production)

place. Every week, after withdrawing finished jobs and adjusting for urgency (in this plant, machines being made in sets of 6 or 12, urgency often developed on the sale of a machine for early delivery) the whole frame was photographed, a copy being sent to the foundry as instruction for the sequence to be followed during the ensuing week. Holidays or other reductions of output capacity were represented by cards scaled to the amount so lost. In slack times similar blocking cards indicated reduction of output capacity, due to the reduced working force.

The **Gantt loading chart** (Fig. 15) depends on much the same principle, but lines are used instead of cards. In the figure each horizontal line represents a machine. Time is represented by the width of the column. The time during which the machine will be occupied by a given job is represented by a thin horizontal line. Heavy black lines show the cumulative accomplishment of the work on the machine. The vacant spaces between the thin lines represent unassigned periods. These are available for assignment of fresh jobs. When Gantt charts are divided by days, Sundays and holidays should be omitted, and only working days shown.

Fig. 16 shows a Gantt-type loading chart for a 30-doz. lot of refrigerators, of which the corresponding master or program schedule is shown in Fig. 33. In this case verticals represent working hours.

Machine	Parts	Machine Hours
Rip Saw		32.4
Cross Cut Stiles & Rails		39.8
Cross Cut Panels	C.O. Panels — Rip Panels — M B M. & Wide Rails	20.0
Mortise #1	Side Stiles — Side Stiles — Front Stiles — Front Rails — Munt.	40.0
Mortise #2	Door Stiles	24.0
Tenon	Side Rails — Front R. — Door Rails — Sides — Fronts — Doors	37.5
Sticker	Side Rails — Side Stiles — F.R — F.S. — D.R. — D.S. — M M&B	28.0
Relish	Side Rails — Front Rails — Door Rails	25.5
Sander	Panels — Sides — Fronts — Doors — Tops — M.M.&B.	40.0
Shaper	Door Panels — Tops	32.6
Rabbiting	Doors — Side Panels	27.0
Glue	Sides — Fronts — Doors — Tops	39.6

Fig. 16. Machine Load Chart Showing Standard Hours Per Machine (as developed from Time Study) for a 30-Doz. Lot of Refrigerators. (Corresponding Master Schedule for this order is shown in Fig. 34)

Loading charts can also be applied to **labor** working without machines. Fig. 17 illustrates a chart assigning labor as expressed in **man-days** (instead of machine-hours) to various working points during repairs on a steamship.

A **flexible device** utilizing the basic Gantt chart principle—the Kardex Sched-U-Graph—also provides the means for a practical machine load-

ing and scheduling record. In the system illustrated in Figs. 18a and 18b, pockets 40 in. long by 5 in. high are used.

Four forms are used: an 8-in. wide index card of the machine, placed at the left; a 32-in. title insert carrying the row of dates (1 to 31); a large-sized operation record card (10 x 3 in.), divided along the bottom and top into inches and tenths for charting machine load in tenths of a day (100 periods), and having a red horizontal band above the bottom numbers; and a small operation record card (3 x 3 in.) the right half ($1\frac{1}{2}$ in.) of which is divided along the bottom and top into tenths of a day (15 periods) with a red band above the bottom numbers. These forms are placed in 40-in. wide pockets with $\frac{3}{8}$ in. wide transloid tips along the bottom edges into which the forms are inserted. The pockets

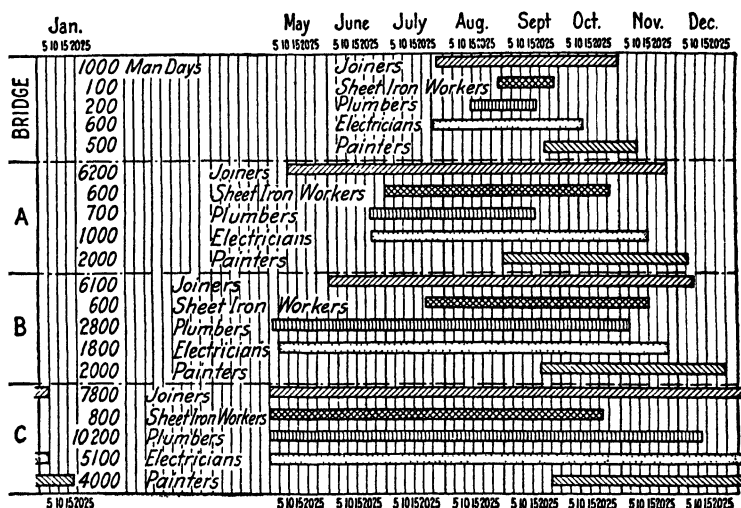



FIG. 17. Assignment of Labor to Various Decks for Ship Reconstruction

are fastened in overlapping series, leaving the transloid edges visible, and are mounted on boards. The title insert is folded along the bottom to turn up the row of dates (1–31) and placed at the right in the pocket with these dates showing beneath the transloid protector. The machine index card—carrying data describing the machine and having the machine number and name, and (in pencil) the number of hours per day the machine is operated, along the bottom edge—is placed in the transloid tip at the left.

For the longer jobs, the long operation record cards are used. Data on a job are entered in the operation record spaces at the left of the card. The number of days, figured in tenths, which are required to complete the job (taking account of the daily running time of the machine) is calculated and the card is cut off at this number, and put into the pocket

HOURS REQU	MACHINE HOURS PER DAY																	HOURS REQU
	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
1	1 25	1 11	1 00	91	83	77	71	67	63	59	56	53	50	48	45	43	42	1
2	2 50	2 22	2 00	1 82	1 67	1 54	1 43	1 33	1 25	1 18	1 11	1 05	1 00	95	91	87	83	2
3	3 75	3 33	3 00	2 73	2 50	2 31	2 14	2 00	1 88	1 76	1 67	1 58	1 50	1 43	1 36	1 30	1 25	3
4	5 00	4 44	4 00	3 64	3 33	3 08	2 86	2 67	2 50	2 35	2 22	2 11	2 00	1 90	1 82	1 74	1 67	4
5	6 25	5 56	5 00	4 55	4 17	3 85	3 57	3 33	3 13	2 94	2 78	2 63	2 50	2 38	2 27	2 17	2 08	5
6	7 50	6 67	6 00	5 45	5 00	4 62	4 29	4 00	3 75	3 53	3 33	3 16	3 00	2 86	2 73	2 61	2 50	6
7	8 75	7 78	7 00	6 36	5 83	5 38	5 00	4 67	4 38	4 12	3 89	3 68	3 50	3 33	3 18	3 04	2 92	7
8	10 00	8 89	8 00	7 27	6 67	6 15	5 71	5 33	5 08	4 71	4 44	4 21	4 00	3 81	3 64	3 48	3 33	8
9	11 25	10 00	9 00	8 18	7 50	6 92	6 43	6 00	5 63	5 29	5 00	4 74	4 50	4 29	4 09	3 91	3 75	9
10	12 50	11 11	10 00	9 09	8 33	7 69	7 14	6 67	6 25	5 88	5 56	5 26	5 00	4 76	4 55	4 35	4 17	10

Fig. 18a. Operation Record Cards Used with Fig. 18b

Fig. 18b. Flexible Machine Loading Chart

with the left end at the day and hour when the job is to be started. The red band thus exposed in the visible transloid tip represents the hours of machine load of the job, and the position of the card, horizontally, shows just which hours are taken up. Where white spaces occur between the sections of red bands, no work is scheduled for the machine. The small operation cards are similarly handled for jobs of a day and a half or less.

Scheduling, of course, must take account of the time when materials or parts will be available to go on the machines. If changes in scheduling must be made for more effective machine loading, taking care of rush orders, etc., it is necessary merely to move the cards. No erasing of charted data is necessary, and the operation data on the job and the red band denoting the over-all time required, are moved as a unit.

For companies preferring to chart by days of the week, title inserts are available printed with the names of days instead of dates, each day represented by one inch of width, divided into tenths. These inserts come with Sundays included or without Sundays, whichever the user prefers. A date strip is put at the top of the board on which this kind of chart is used.

Like the Gantt chart, the Sched-U-Graph thus graphs not only the load on each machine, but the exact times when the machine is loaded. Among the large manufacturers using this device in the above-described fashion with variations to suit their own needs are Douglas Aircraft, Bell Aircraft, Curtiss-Wright, Pratt & Whitney, Allis Chalmers, DeVilbiss Co., General Cable Corp., etc.

Tabular forms of loading control are sometimes preferred in repetitive work and mass production. Fig. 19 is an example. Total operating capacity for the period appears above the name and number of each machine. Each horizontal line takes care of one lot. The quantity of each part to be manufactured in the period is converted into machine-hours from recorded data. The resulting figure is entered under the

Date Received	Month	Piece Part	Quantity	Deliver to Dept.	OPERATING CONDITIONS — Machine Capacity in Hours 42 832 — Man Hours Available 46 700 — Type of Machine									HELD FOR							Date Promised	Date Completed	Dept.____ Month____ REMARKS
					11032	978	580	1296	6173	604	12874	3171	180										
					BENCH	#1½ BLISS	#3½ TOGGLE	#3½ #4 BLISS	#7½ #7&65 BLISS	#6 VERMONT	#78 #21 BLISS	#13½ #7½ BLISS	FOOT PRESS	Tools	R. M.	From Dept.	Mach. Repair	M F Parts	Help	Complaint			
7 2	7	87 527	150000	6343	1400						700			C 16473									HELD FOR TOOL ON CHANGE ORDER W-745364
7-2	7	87 530	75000	6352 6336	290 1600	120					140 840	120									9 20		DAILY 4000
7 2	7	88 598	25000	6338				90			120 960										9 22	9 21	COMPLETED
7-29	8	93 490	150000	6332 6336	901 2501	110 230					740 1700	300 420	116								9 22		DAILY 5000
7-29	8	93491	310000	6357				130 220		122	180 1890										10 2		
7-29	8	94 394	75000	6332	401 2902						1010 2900										9 21		DAILY 5000

FIG. 19. Operating Conditions Report Kept by Each Operating Department

proper type of equipment. The upper figure represents hours on the job; the lower figure, the **cumulative loading for the period** as far as posting has gone. The cumulative total in any column when balanced against the total capacity shown at the top of the column shows any condition of over- or underload.

A simple ledger form of control, suitable for a small shop is given in Fig. 20. Each weekly division is headed with the number of working hours in the week. Orders are then posted to the machine (one such

blank being used for each machine) and the operating time allowance is deducted from the total weekly capacity. The next job is treated similarly, but the time is deducted from the previous balance. The column "balance of load" always shows what unallotted capacity is available in any week ahead. Jobs which go over the total weekly capacity are split up, part of the time being allotted to the week ahead (cf. Order 37626 on figure). In small shops this form of loading control can be used as a **progress control,** if jobs are legibly marked off or blocked out as completed.

Influence of Sequence on Machine Loading.—Specification of sequence at the operation study stage is better limited to cases in which technical reasons made it essential. An example of the way in which machine loading is affected by fixed or flexible sequences is given in Figs. 20, 21, and 22.

MACHINE *11'' Norton Grinder G78*

Week Ending *May 6* Hrs. *48*				Week Ending Hrs. *40*	
Order	Part	Time	BALANCE OF LOAD	Order	
37614	*2M36*	*12*	*36*	*37626*	
37614	*4J17*	*15*	*21*		
37626	*61L6*	*#21* *(part)*	—		
	(30 hr. Job.		*9 hrs.*		
	carried to next week)				

Fig. 20. Machine Loading by Means of Weekly Schedule Record

Fig. 21 represents a program or master schedule of a product made up of six components and five assemblies. The latter will be omitted from the discussion. This schedule may represent the construction of a special machine, the scale being read in hours; or the manufacture of a batch of machines, in which case there will be, for example, 100 pieces in each of jobs A, B, etc., and the scale will read in days. The shortest possible time in which the machining can be put through is 22 hr., which is the sum of the time allowances for part E.

Fig. 22 illustrates the assignment of work to various machines Nos. 31, 46, 48, etc., when the sequence of operations on the various parts is not fixed, i.e., the operations can be taken in any order convenient. All operations of all six parts can be so loaded as to reach completion within the minimum set by part E, namely, 22 hr.

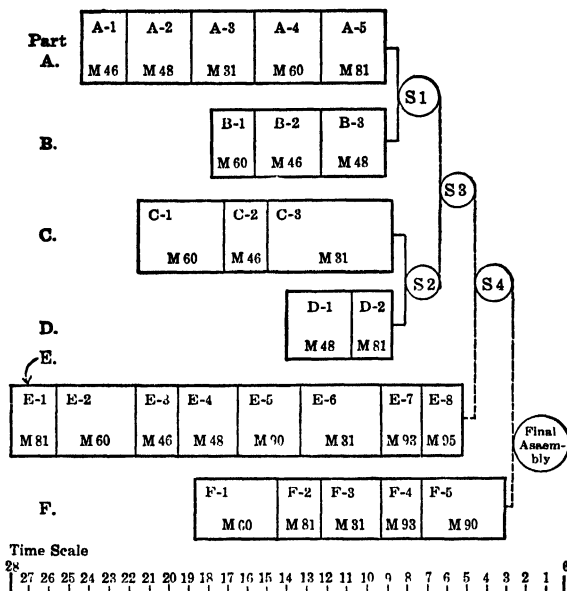



FIG. 21. Master Schedule of Assembled Product, Made up of Six Components (A-F)

See Figs. 22 and 23 for corresponding machine loading. (Note: Components taken out of stock for assemblies 51, 52, etc., are omitted from the diagram.)

MACHINE	TIME SCALE 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
31	A-3 C-3 E-6 F-3
46	E-3 A-1 B-2 C-2
48	E-4 A-2 B-3 D-1
60	B-1 E-2 A-4 C-1 F-1
81	F-2 D-2 A-5 E-1
90	F-5 E-5
93	F-4 E-7
95	E-8

FIG. 22. Machine Loading of Product from Fig. 21 When Operation Sequence Is Not Fixed, 22 Time Units

In Fig. 23 assignment to machines is conditioned by instructions that sequence of operations is to be as indicated on schedule, 1, 2, 3, etc. In this case completion of the last process on the last part (F5) is not reached until 34 hr. (instead of 22 hr.) after start.

In the first case, moreover, machine loading is closer than in the second. With open sequence, machines 31–81 are so loaded that gaps between jobs amount only to 4 hr. With fixed sequence, gaps on the same machines are 28 hr. For all machines the gaps amount to 15 hr. in open sequence and 51 hr. in fixed sequence.

If the master schedule is read as pertaining to a lot of 100 machines, production being in days, a third modification of loading is possible. Simultaneous or overlapping production in which a second operation is started on a lot as soon as one day's supply from the previous operation is available, permits of machines being so loaded that the last machining operation takes place in 27 days from the start, although the fixed se-

MACHINE	TIMESCALE 1–34
31	A-3, E-6, C-3, F-3
46	A-1, B-2, E-3, C-2
48	A-2, B-3, E-4, D-1
60	B-1, E-2, A-4, C-1, F-1
81	E-1, A-5, D-2, F-2
90	E-5, F-5
93	E-7, F-4
95	E-8

Fig. 23. Machine Loading of Product from Fig. 21 When Sequence of Operations Is Invariable and as Scheduled, 34 Time Units

quence as a schedule is maintained; 21 days of gap for machines 31–81 are required in fitting in jobs. This result is intermediate between the two cases for which charts are given.

In practice, machine loading is rarely carried to the degree of compactness shown in Figs. 21 and 22. It is usual to space successive operations so that one day or more lies between them. This plan is followed to form a **cushion of work** which can absorb slight delays without disturbing schedules. It is claimed, also, that there is a psychological effect due to the presence of "plenty of work" awaiting its turn at a machine. If the loading had been arranged, in the cases just mentioned, on this cushion plan, the only effect would be to extend the period during which work was in shops. Actual machining time would not be affected. Incidentally, these charts demonstrate the nature of the machine loading problem, and why unplanned work is likely to give rise to confusion and delay in the endeavor to give each job its proper turn by main force, instead of by studied method.

Machine loading is controlled at the Eaton Manufacturing Co. by a system combining an equipment record card in the top holder of each pocket of a **visible record system** and a buff machine load record in the

lower holder. Cards for machines of a similar kind are grouped together. As each job is scheduled to a machine the data are entered on the card, which has columns for model, part name, part number, operation, pieces per set, total pieces required per day, production per hour (estimated, actual), required hours per day (estimated, actual), total, potential production per hour, and remarks. An orange Graph-A-Matic movable signal is set on the visible margin at the right over a scale of the 24-hr. day to show the estimated hours per day the machine will be run. When time studies are completed a green Graph-A-Matic signal is moved to show the number of machine-hours required to produce the total quantity of pieces scheduled for the day. From this record the machines available for additional work can be picked as new jobs are scheduled.

Under this system, since cards for similar machines are grouped, salmon machine load summary cards are used to separate the groups and on these latter cards, in each case, the total load hours per day, both estimated and actual, for the group are accumulated. A green signal at the right of each summary card shows the percentage of capacity which is in production for that class of machine.

In the Bendix-Westinghouse Automatic Air Brake Co., scheduling and machine loading are handled on an Index-Visible system kept in the production department. Three employees schedule and post the assignment of 15,000 orders in the set-up. The machine load card for each posting is prepared by a multigraph process when the production order and payroll cards are duplicated, a separate card being made for each operation. Across the visible top of the card are spaces for part number, quantity, operation, schedule dates, and total time. Other data below are order or account, delivery schedule, part name, rough size, pieces per hour or day, material specification, operation, department, machine number, description of operation, tool list, standard time, and columns for entering dates of production, quantities produced, and balances due. Each operation is then assigned to a specific machine by filing the card under a salmon master card designating the particular machine. The total time required for the operation, which is shown at the right of the visible margin on the card, at the same time is added into the total hours' work ahead of the machine and the new total is posted on the salmon card. When the job is put into production the operation card goes with the material to the machine, where the daily quantities produced are posted to the card and balances due are thus determined.

The **objective of machine loading** being (1) to assign jobs in due sequence for completion at or near a given date ahead, (2) to keep each machine supplied with a continuous flow of jobs, it follows that **idleness of machines** must be made a matter of careful record. Loss of machine production can arise from many causes, apart from failure to plan a continuous supply of work. Breakage of machine parts, of tools, of jigs and fixtures, lack of material, absent operatives, may all contribute. The amount and cause of idleness should be tabulated for each machine in each department, and a summary prepared, as illustrated by **Fig. 24**, for executive information. In this report a Gantt chart shows the amount less than 100% run by each class of machines, also total expense of time lost, classified under headings, such as "lack of orders,"

WORKING PERIOD 5 WEEKS... DAYS... HOURS PERIOD ENDING Sept. 3. 19 Lower Throwing.... MILL

TOTAL MACHINE EXPENSE USED .... TOTAL UNUSED $233.32 TOTAL MACHINE TIME UNUSED 6.5 PER CENT TOTAL CREDIT 0.... PER CENT

SYMBOL	DEPARTMENT OR MACH. CLASS	PER CENT OF TIME MACHINES RAN 10 20 30 40 50 60 70 80 90	DETAILS OF EXPENSES OF IDLENESS DUE TO						TOTAL	REMARKS
			Lack of Orders Note 1	Lack of Help Note 2	Lack of Material	Caught up to Next Dept.	Repairs			
	Total		50 85	178 56			3 91		233 32	
	Winders			101 40					101 40	
	Doublers			43 38					43 38	
	Spinners		50 85	99					51 84	Note 1 This Expense is incurred because this Machine is used for
	Hosiery Spinners			8 28			3 91		12 19	Special Coarse Sizes and is idle due to Shortage of these Sizes.
	Twisters									
	Transferring			16 11					16 11	Note 2 Lack of Help does not mean an Actual Need of Help
	Stretchers			53					53	but means Workers are out at Intervals
	Reels			7 87					7 87	

FIG. 24. Gantt Machine Idleness Expense Chart

etc. At the head of the report, figures are consolidated for the whole plant showing the value of machine-hours unused, and the total percentage unused.

Where jobs are heterogeneous in character, as in repair shops, close assignment to machines is usually impossible. Order of jobs on machines is replaced by assignment to "periods" of two, three, or more days. In some industries each month is divided into two or three working "periods," and jobs are first assigned to these periods. The order of work on machines can then be worked out closer as the period approaches, though in some cases reliance is placed on a "tracing" method to bring work up to machines in reasonable order and time.

Elements of Operating Procedures for Control

MANUFACTURING OR PRODUCTION ORDERS.—Authorization to commence production is given by manufacturing or production orders. Manufacturing orders may be **actual** or **virtual.** In custom work they are always the former. Each production order deals with a specific order as received from the customer. In mass production and in continuous industries, they may be virtual, that is, simply an understanding that a certain output is to be maintained over a coming period. Even in the latter case some device must be adopted to distinguish production of one period from that of another. Monthly outputs are frequently used in this way. Instead of charging them to a specific order number, the charges are made to each specific month's production.

Objectives aimed at by the issue of manufacturing or production orders are: (1) to convey information as to customer and promised time of delivery; (2) to serve as a nucleus for cost collection either for the order as a whole or for individual components and processes on components; (3) to form a starting point for the control mechanism.

Subsidiary Orders.—In machine-shop work, a production order initiates a whole series of subsidiary orders, among which are: pattern and casting orders; tool, fixture, and jig-making orders; processing or job orders; all of which are extensions of the productive process. The control mechanism requires, in addition, material requisitions, stores-issue orders, tool-issue orders, move orders, inspection orders, and replacement orders.

Date_____To be shipped on___ 7963
Customer__________
Shipping Instructions __________

Order for_____Pieces_____Pattern
Material__________
Finish__________

Customer's Order No. _____Dated_____

FINISHING 7963

Man______Machine______

Begun_____Fin.____Time_____

Pieces Rec'd_____ Spoiled_____

Pieces Good_____ Insp._____

MOLDING 7963

Man______Machine______

Begun_____Fin.____Time_____

Pieces Rec'd_____Spoiled_____

Pieces Good_____Insp _____

MATERIAL 7963

Rec'd by________Time_____

Fig. 25. Combined Production and Job Order Where Routing Is Fixed

In small plants and in industries with fixed processes, manufacturing orders are sometimes consolidated with the routing and even the scheduling mechanism. Fig. 25 illustrates the former type. Stubs are detached and sent to the planning department as soon as each operation is performed. The top stub represents the manufacturing order and the lower ones process or job orders, the first to be detached (at bottom) being a material-issue order.

Fig. 26 shows a production order for mirror manufacture. The right-hand portion serves to schedule the order. Symbols *A*, *B*, and *C* indicate first, second, and third "periods" into which monthly production is divided.

In Fig. 27 a production order is shown based on a different idea. Here it is not a question of specific customers' orders, but of authorizing production of so much of each size and kind of fabric during one week. In most cases such authorization will be based on a consolidation of orders from customers already in hand. It may also include an anticipation of marketing needs. This procedure really amounts to a manufacture of goods for stock, whence they will be divided up into lots as ordered by each customer.

In **engineering work** and in **assembly industries** of similar character, the manufacturing order sometimes is more in the nature of a memorandum of identification, together with a record of the successive steps in filling the order. It may provide for: (1) customer's name, address, order number, and shipping instructions; (2) date promised for delivery; (3) description of goods to be made. These brief particulars must be

CHARGE TO: John Widdecomb & Co LOT: 5 ORDER NO. 6000

SHIP TO: Grand Rapids, Mich SOLD BY: J L CUST NO 4001

VIA	RECEIVED	Oct	1	19—	WANTED PROMISED	Oct	31	19—
		MO	DAY	YR		MO	DAY	YR

SIZE		BEV	SILV	PATTERN	QUAL	PLATES	REMARKS	DATE CUT	SCHEDULING ACID	POL	BEV	PF	MIT		SILV
18"	X 30"	—	✓	plain	I	50		3		A 50					A 50
12	X 20	—	✓	"	I	200		4, 5 & 6		A 50 B-50					B 100
22	X 40	—	✓	"	I	150		8 & 9		B 150					B 150
15	X 28	—	✓	"	III	100		10 & 11		B 100					C 100
36	X 60	1"	—	342 a	I	10	See previous order #3562	10			C-10	C 10			

FIG. 26. Production Order Combined with Schedule

supplemented by parts lists providing columns for: (1) pattern order numbers; (2) casting order numbers; (3) tool, jig, and fixture-making order numbers, if required; (4) process or job order numbers. In repair work or any work of few components, all these particulars may be listed on the order itself. The actual form of such orders varies from plant to plant, and their number is legion. Fig. 28 shows one type as used by a machinery-making plant.

Production orders are usually **manifolded,** copies being sent to all departments in which work is to be performed on the order. This plan is usually followed as a means of reference and identification, even though all definite working instructions are contained in other documents.

The **receipt of a manufacturing order** by the planning department sets the activities of that department in motion. The material situation receives first attention, stock is reserved on the stores records, requisitions for purchases are made, and the question of making or buying outside is settled. The times at which purchased materials will be available are ascertained as closely as possible. The way is then open for the specific work of control to be set going. If the operation study has not been already completed by the engineering department, that must now be

done, at least to the stage of specifying the machines to be used, and all fixed sequences of operations that may be necessary. With this information at hand, route sheets may be set up while time allowances are being settled.

KNITTING ORDER
for

Serial No. 46

Mill No. 6   Week of 10/10/ – to 10/17/ –   Date 10/1/ –

FABRIC	7½	8	8½	9	9½	10	10½	11	12	12½	13	14	15	16	17	18	19	20	21	22	23	24	25	26	GRAND TOTAL
4639	Machine Numbers Cloth Order												2-16 600	3-5 700	7-10 700	8-11 1700	9-12 240	14-17 300	16 300	17 360					4900
4940	Machine Numbers Cloth Order										18-1 400	24-26 500	28-30 600	30-40 700	42-41 700	46-47 700	49-60 800	68-66 400	67-65 400	63-61 400	79-78 400				6000

Fig. 27. Production Order Authorizing Weekly Outputs

CONTROL OF MANUFACTURING.—Control of operating procedure in the manufacturing departments includes, (1) determination as to **where the work is to be done;** (2) determination as to **when the work is to be done; (3) seeing that the work is done,** by providing mechanisms and procedures for issuing the orders which put these determinations into effect. This latter step also covers the gathering of information on the progress of the work, and making revisions as to place and time when changes in the original plans and schedules become necessary.

The first of the above tasks is known as **routing;** the second as **scheduling;** and the third as **dispatching.**

B 82

PRODUCTION ORDER C

CHARGED TO / ORDERED BY John Doe   SHIP. ORDER NO. 38700

SHIP PREPAID / COLLECT TO John Doe, New York   WEIGHT ____ HOW PACKED

VIA Express

F.O B. Providence   SERIAL NO.

	DATE ORDERED BY CUSTOMER			SHIPPING ORDER ISSUED			SHIPMENT DUE		
	MONTH	DAY	YEAR	MONTH	DAY	YEAR	MONTH	DAY	YEAR
	4	15		4	15		4	17	

TERMS Net 30 Days   CUSTOMER'S ORDER NO 40   REQ. 730

Item	Quantity	Description	Drawing No	Check	Pattern No	Stock M'f'g. Purch.	Symbol	On Hand		Shipped	
1	100	#2 Change Gears 72T 16P 7/16" F	11701-D-72			WM	Rav 11701-72 G2R	/	/		
						PM		–	–		
						P		–	–		

CUSTOMER'S ORDER REC'D		SHEET WRITTEN AND APPROVED		ORDER WRITTEN		DRAWINGS AND DATA CHECKED		ISSUES WRITTEN		MATERIAL APPORT ND		PASSED	SHIPMENT COMPLETE		BILLED		ENTERED ON RECORD	
GL		CSB		MM		CSB		RT		JS		FG	RH		DH		JH	
DAY	HOUR	DAY	HOUR	DAY	HOUR	DAY	HOUR	DAY	HOUR	DAY	HOUR	INSPECTOR	DAY	HOUR	DAY	HOUR	DAY	HOUR
4/15	1	4/15	2	4/15	3	4/15	2	4/15	3	4/15	3	4/15-3	4/15	4	4/15	5	4/15	5

WM = Worked material. PM = Plant foundry materials. P = Purchased material. The two checks in the "On Hand" column indicate that material is on hand and ready to ship.

Fig. 28. Production Order Identifying Product and Recording Successive Steps in Filling Order

Elements of Routing Procedure

THE ROUTING FUNCTION.—As frequently employed, the term "routing" is very indefinite. It is often used to include every step from the first contemplation of a product with a view to manufacture, through machine analysis, analysis into parts, and operation study down to the preparation of orders and documents of which the release sets production going. It is also applied to the flow of material and of work in process. Conveyor assembly systems as developed in automobile and other plants are sometimes cited as examples of good "routing." Evidently such a use of the term has little in common with definite steps for getting actual orders into work. It is better to confine the term to the actual preparation of route sheets, leaving other steps to appear under more definite headings.

Events in the history of manufacturing a product, if considered in sequence, will serve as an introduction to a systematic presentation of the steps inherent in production control. In engineering and machine-shop practice, these steps occur as follows:

1. At first the future product exists only as an idea, possibly embodied in sketches.
2. Next, the more important or novel details of the idea are studied at length, and drawings prepared to develop them.
3. When finality has been reached on the novel features, working drawings of the whole machine or other product are prepared.
4. Working detail drawings of parts and assemblies are made, with blueprints and all technical data.

Where standardized or repetitive work is in question, the best practice demands that the foregoing design of parts and details shall have been simultaneous with—

a. Consideration of the processes and operations by which the part is to be made.
b. Consideration of the most suitable material, having regard to the use of the part and also to exigencies of manufacture.

In this case the **completed design** as received from the engineering division by the production control office will include:

1. List of parts, and assemblies.
2. Working drawings (blueprints) of each part and assembly.
3. Specification of kind and quality of material for each part.
4. Inspection data (limits and tolerances) on each part.
5. Specification of machine processes by which a part is to be made.
6. Sequence in which these processes are to be done.
7. Time allowances for each process, subdivided into (a) setting-up time, (b) operation time.

In **custom work** and in less standardized manufacture, the work of the designing division may end at item 4 in the second list above. Detail drawings (which in many cases may be supplied by the customer) give simply form, dimensions, tolerances, and material of which the part is to be made, leaving the actual method of manufacture to be decided by the production control department.

It is this latter case that will be assumed in the following discussion, and each step to be taken will be treated in a separate paragraph. The

term "routing" will be confined to preparation of route sheets and orders and papers controlling the movement of material and the stages of production.

In **nonengineering industries** the route of the work is often fixed and invariable. In some cases, e.g., shoe manufacture, dissection of a pattern or model provides a list of separate parts and of the kind and quantity of material requisite, but there is little choice as to the way in which it is to be made. In **continuous industries** processes and their sequence are wholly fixed, although successive batches of product may vary in composition. In applying the procedure now to be described to other industries, such links as do not apply should simply be omitted. Further, it is on the objective of each step that attention should be directed. If this fact is understood the corresponding point of the objective in other industries will be easily grasped.

PREPARATION OF ROUTE SHEETS.—Route sheets deal with **specific manufacturing orders** (actual or virtual). One sheet is required for each part or component of the order. On such a sheet are assembled working data for controlling the passage of that piece through the shop. In large plants route sheets are usually departmental, operations in each department being listed separately. The data usually included on a route sheet are as follows:

1. Number and other identification of order.
2. Symbol and identification of part.
3. Number of pieces to be made.
4. If put through in lots, how many in each lot?
5. Operation data, including:
   a. List of operations on the part.
   b. Departments in which the work is to be done.
   c. Machine to be used for each operation.
   d. Fixed sequence, if any, of operations.
6. Rate at which the job (or first lot) must be completed. The data for this entry will be obtained from the standard time per piece or lot as noted on the operation sheet.

Spoilage and Stock Allowances.—A spoilage allowance is required, and a waste allowance, if the part is to be made from raw materials. In many cases, also, opportunity is taken to make for stock extra pieces either as a reserve, or for sale as spares or repair parts. In repetitive work these two allowances may be combined into a single percentage. The allowances give a factor greater than unity which, multiplied by the number of pieces on the order, yields the correct number to be put into process on each occasion.

Stores issue orders, time cards, and other working papers may also be prepared at this time but often are written in a separate section of the production control department.

USE OF ROUTE SHEETS.—Route sheets serve as histories of the progress of a part through its cycle of operations. They are also used:

1. To check up subsequent steps of control and shop procedure.
2. To register progress of the part from start to completion and delivery to stores or to assembly.

Fig. 29 illustrates the general arrangement of a route sheet for machine-shop work.

ROUTE SHEET Order No. ______ For ______ Date of Completion ______

Description of Part ______ *Front Disc.* ______ Part Symbol ______ *B* ______

Number of Pieces on Order or in Lots ______ Spoilage Allowance ______ Extra Stock Allowance ______ Total to Make ______

Material Symbol ______ Description ______ Quantity Allotted ______

Purchase Order No. ______ Due ______ Stores Issue Order No. ______ Move ______

OP NO	TOOL		OPERATION	MACHINE	TIME ALLOWANCE				DUE DATES		MOVE ORD	PIECES GOOD						
	MAKING ORDER	ISS			PER PIECE	LOT	SETTING	TOTAL	BEGIN	FINISH								
1			*Shearing Sheets*	*Gate Shears*														
2			*Cutting Circles*	*Circle Cutter*														
3			*Forming dies*	*Press*														
4			*Punch rivet holes*	*Press*					←	A		→						
5			*Trim & Roll edge*	*Lathe*														
6			*Valve guard notch*	*Punch*														
7			*Dress V. G. notch*	*Hand*														
8			*Retrim*	*Circle Cutter*														

FIG. 29. General Arrangement of a Route Sheet for the Manufacture of a Part

If product is put through in periodical lots, additional columns as "A" provide for necessary data.

ROUTE SHEET Order No. 6192	Name			Price Number	
	14" H. S. Apron			25-A-224	
	Date Started	Material	No of Sheets / Sheet No	No of Pcs.	Lot No.

Op No	Operation	Dept	Mach.	Tool List	S U T	S.T.	INSPECTOR'S REPORT O K	Spoil	Date	Sign
1	Rgh. & Fin. Plane	24								
2	Rgh. & Fin. Mill Pads & Bosses	22								
3	Rgh. & Fin. Mill for Rack Pinion Gear	22								
4	Scrape Apron Seat to Plate	78								
5	Drill & Tap for Carriage	26								
6	Drill & Tap for Pinion, Handwheel & Clutch	26								
7	File Burrs & Round Corners	88								
8	File, Rub & Shellac	14								
	Move to Stock # 85									

FIG. 30. Route Sheet Which Follows Through a Plant Repair Order

NAME OF PIECE	SYMBOL	PIECE NUMBER
TAILSTOCK TOP	D	51796

OPERATION NO	OPERATION	ALLOWANCE
S-1	Grind & clean	
DD-2	Plane complete Tl#16478	0.75
I-3	Drill for clamp bolts Jig#13730-3-11	0.25
---	Break edges (No time ticket)	
HH-4	Order base #D-985	
A-12	Layoff for key & oil	
EE-13	Drill for key & oil	0.25
HH-14	Rough ream	0.75

FIG. 31. Routing Card Showing Operations and Time Allowances

In filling out a route sheet, the time allowance for each operation cannot be entered until operation sheets are available. Similarly, "due dates" for beginning and completing each operation cannot be inserted until such dates have been determined by scheduling.

Fig. 30 illustrates a route sheet as used for repair orders. In this case the route covers several departments, and the sheet is attached to the identification tag of the lot and accompanies it from one department to the next.

Fig. 31 shows a Lodge and Shipley routing card detailing operations throughout the plant, including time allowances where made.

The same objective will be found in all these sheets, however different the ruling and method of use. Identification of different operations on a single component, with some mechanism for checking off each as completed, is the minimum requirement. In a fully developed sheet, such as Fig. 28, times and quantities are included, and such sheets may form an element of a control board system.

Further entries in route sheets will be considered after scheduling has been given attention.

Elements of Scheduling Procedure

DEFINITION.—Scheduling may be defined as:

> Fitting in of specific jobs into a general time-table, so that orders may be manufactured in accordance with contracted liability, or, in mass production, so that each component may arrive at and enter into assembly in due order and on time.

Scheduling involves the preparation of (1) a **preliminary or over-all schedule,** adjusting expected requirements with available capacity, and (2) a **detailed schedule** in terms of specific jobs or orders.

PRELIMINARY SCHEDULING.—The objective of preliminary scheduling is to determine approximately, the quantities of each variety of product to be made in a future period, and to collate the call on manufacturing capacity thus set up, with the normal manufacturing capacity available. The order or sequence in which different items are to follow each other, i.e., approximate "periods" in which specific quantities are to be manufactured, is usually an essential feature.

In preparation for this determination, the "master" schedules should be compiled for each separate line of product. These schedules should show, at least approximately, the time required to process each item, and hence to carry along a unit quantity of product through all stages of manufacture. A relation between **quantity** (of product) **and time** being thus set up, the question whether the proposed program is above or below normal productive capacity of plant can be settled with reasonable closeness.

Preliminary scheduling should only be general in character and not pinned down to specific dates. Often more waste in time and dollars comes from starting before continuity in processing is assured than from any other single cause. If a date is assigned before the material is at hand and before the loading charts have been consulted, either a start is made at the scheduled date or the schedule is altered. Either

LOCOMOTIVE DEPT. SCHEDULE 18-DAY REPAIR PERIOD DATE... .....19..					
Days in Shop	Operation				
	Erecting Shop	Boiler and Tank Shop	East Machine Shop	West Machine Shop	
1	Engine in Shop Engine off Wheels	Netting & Plates out			
2	Steam & Exhaust Pipes out General Stripping Completed	Hydro Test Ashpan Down			
3	Headers Out. All Material Cleaned and Delivered	Chip Tube Beads	Strip & Clean Wheels, Boxes, Crossheads & Pistons	Clean & Test Main & Side Rods & Deliver to Smith Shop	
4	Cylinder & Valve Bushes Inspected	Cut & Remove Tubes Complete		Strip & Clean Motion New Parts Ordered	Al ce
5	Old Cyl & Valve Bushes Cut out	Boiler Work Started			
6	Cylinders Patched				
7				Motion Pins to SS M & S Rods Received	
8	Cylinder & Valve Bushes Rebored	Tubes Welded	Bottom Splices Cylinder Bushes		M
9	Guard Stays Up Shoes & Wedges Laid off	Coppers Applied	New Shoes & Wedges Box Sizes, Widths O K Top Splices, Valve Bushes		
10	Mountings in	Tubes in Boiler Work Completed	Crossheads	Guide Bars Dry Pipe	
11	Spring Gear Up Guides & X-Heads Lined	Boiler Tested	Wheels	Motion, Valves	
12	Engine Wheeled Headers in Motion Hung			Bell Stand	
13	Pump O K		Smoke Stack Base Smoke Stack Hood	Main Rods, Eccentric Rods	In
14	Valves Set, Steam & Exhaust Pipes in	Tank Repairs O K	Smoke Stack		Wh Lu
15			Piston O. K	Side Rods	All
16	Brake Gear O K.	Ash Pan Started	Eng Truck Idler Wheels		
17	Smoke Box Front on Side Rods on Engine Trucked	Ash Pan O K Netting & Plates O K.			
18	Engine Finished Ready for Trial	Light Work Completed			

FIG. 32. Preliminary or Master Schedule for Locomotive Repair

method is dangerous. The proper plan is to map out relative dates within the job but leave actual dates until they can be fitted into machine loads and shop schedules. The preparation of schedules is considered below. Some examples of master schedules are given in Figs. 32, 33, and 34.

Fig. 32 shows a portion of an 18-day **repair schedule** in a locomotive shop. Note that the sequence of all operations is determined with **relative dates,** but no actual dates until incorporation of the plan in shop schedules has been effected. When all material for earlier jobs is in hand and delivery assured for the remainder, the preliminary schedule can be assigned definite dates on loading charts with reasonable expectation that they will be kept.

Fig. 33 exhibits a **master schedule for a highly standardized** and purely repetitive type of manufacturing. The sequence and relative date of all operations are set out on a carefully determined plan. Maximum efficiency is attained when this master schedule can be transferred unaltered to the actual shop production schedule wherein dates are assigned to each step. It can be expanded or contracted so as to represent less or greater production in any given period.

SCHEDULING ACCORDING TO METHODS OF MANUFACTURE.—The problem of definite scheduling of production requirements is dependent upon the method of production or the manufacturing procedure. Four general situations need to be distinguished, two under intermittent and two under continuous manufacture.

1. **Intermittent or lot manufacture,** in which the product is routed through the plant in lots or job orders. Under this general heading there are, in turn, two general methods of procedure:

a. **Manufacturing to order.** Where orders go through shops to individual parts. Parts may be single pieces or multiples. Each part passes through one to several processes. Assembly is dependent on all parts being ready simultaneously. Examples are simple products such as castings or stampings, finished or unfinished, both requiring assembly.

Orders are not necessarily individual customers' orders. They may represent consolidations of several such orders for identical styles or patterns. Manufacturing orders may also represent estimated stock or sales requirements of a particular item of product, such as 120 gross of a certain style of shoe, 50,000 yards of a certain pattern of fabric, or 12 dozen of a single catalog item, such as a particular window-stand in a shop fittings manufacturer's line.

b. **Stock manufacturing.** Differs from (a) principally in that very large numbers of pieces are involved so that it is more convenient to make parts in large quantities and put into stock to be withdrawn for assembly as required. Parts are put through in separate lots at predetermined intervals over a period. Assembly is an independent operation. It can go on as long as stock parts are unexhausted.

2. **Continuous manufacture,** which is also of two general kinds:

a. **Single-product** continuous manufacturing. Where a single product goes through a fixed series of processes without assembly. Output is usually reckoned in months or weeks, instead of by orders. The only variation is increased or diminished output as demand indicates.

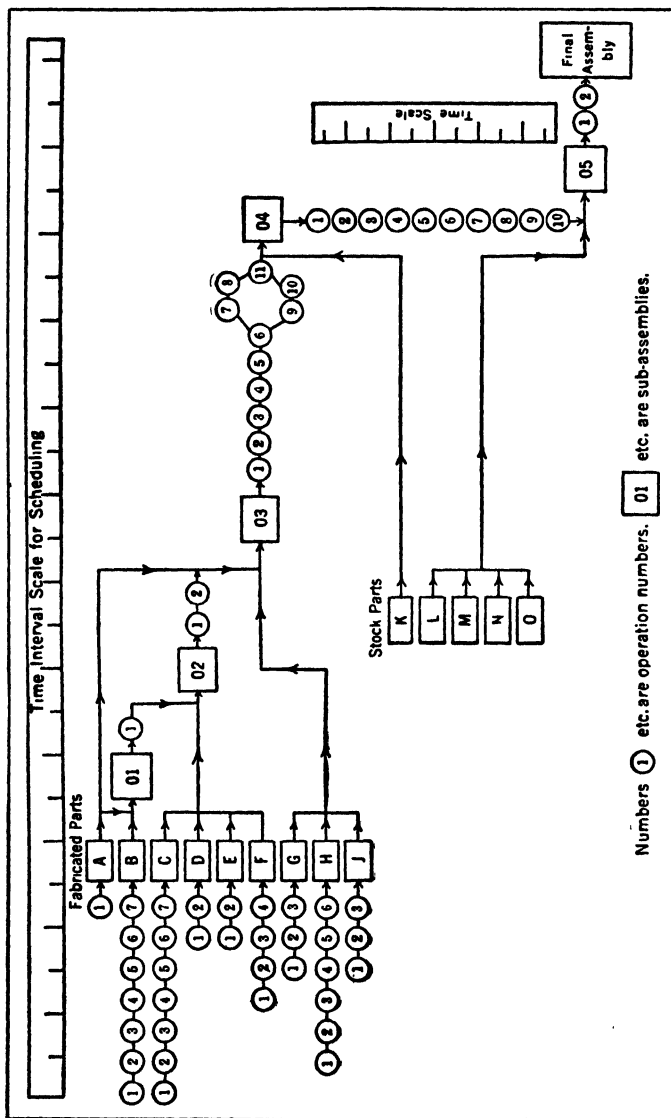



FIG. 33. Master Schedule for Manufacture and Assembly of a Product

b. **Multi- or assembly-product** continuous manufacture, ordinarily known as **mass production.** Where parts or the more important parts are made continuously, each operation having a given output per day, all being proportionately increased or diminished together as demand indicates. From a scheduling standpoint this is equivalent to several separate streams of continuous manufacture, but subassemblies, assembly and simultaneous end processes, increase or diminish with the output of parts.

SCHEDULING FOR INTERMITTENT MANUFACTURING. —Scheduling under intermittent manufacturing conditions embraces three different steps or stages:

1. Scheduling within order or product. Master schedules determine relative dates at which each process on each part or lot should be commenced and finished. (Figs 29, 33, and 34.)
2. Scheduling of order (or of lots in stock manufacturing) in relation to other orders. In custom work this will depend on delivery date of order; in stock manufacturing, on the relative dates at which each component should be completed for stock. Sequence in which each order or lot should be taken up for assignment to machines is thus determined.
3. Scheduling to machines, or machine loading. Date of completion of an order or lot being known, reference to master schedule shows when each process should be commenced. Reference to machine loading charts shows nearest available date for such commencement. When all processes on all parts or lots have been assigned to machines scheduling is complete.

In **custom order** manufacture, and wherever future production depends on outside factors (as opposed to stock and mass production) scheduling often becomes a compromise between time at which a job ought to be done and date at which it can be done, having in view previous commitments. Where work is put through in comparatively large lots, and program is made up months ahead, scheduling, in absence of special or custom orders, is a much easier operation.

In mass production on a large scale, as in the automobile industry and in continuous industries, scheduling is at its simplest development. Output of machines is balanced with reference to continuous flow of product, machine set-ups are rarely changed, specific job orders are unnecessary, and as long as material is delivered in standard lots, at predetermined times, to the first process, movement of work is practically automatic. Parts which have to be made in definite lots for stock would usually be manufactured in a department apart from the main stream of production. In such cases a master schedule covers the whole ground, for its requirements are embodied in layout of machines, which merely require to be kept running to carry out the program.

When scheduling has been completed, **progress control** is set up to insure that the program is actually put into effect, and dates are set for each operation observed. Progress is controlled by route sheets, Gantt charts, or control boards, or by combinations of these mechanisms. In mass production control of progress must be taken care of just as in manufacture by orders and lots. Track must be kept of all **exceptions** to planned routine, such as spoilages, breakdowns, defective work, replacements, etc. Inspection is even more rigorously demanded than with ordinary manufacture, since each process is dependent on the previous one.

Fig. 33, previously referred to, illustrates an example of intermittent or lot **manufacture of a repetitive or cyclical type** usually required when products or parts to be assembled are manufactured for stock. The product is put through in lots of predetermined size, and the same set of processes are repeated over and over again on each occasion. This type is not confined to machine-shop work, having been applied in manufacturing extensive lines of cosmetics and in other industries. Production based on exhaustion of stocks leads to uneconomic manufacturing runs. With a **perishable product,** however, much closer control is desirable.

Fig. 34 represents a **master schedule** for refrigerators in 30-doz. lots, charted on a Gantt sheet. In this case the product has been broken down into operations and machines have been assigned. Vertical columns represent hours, and horizontal lines particular items of product. A 15-hr. cycle results which can, obviously, be doubled or trebled should it be desired to put through lots of twice or thrice the size. In routing this lot, all that is necessary is to assign dates and times by consulting the loading chart, and observing the material situation. Once prepared, a master schedule of this kind remains good until some alteration of product or process is effected. See Fig. 16 for the loading chart corresponding to this schedule.

MASTER SCHEDULES.—Master schedules (Figs. 29, 33, and 34) should be prepared as soon as the product has been analyzed into parts and processes. In stock production, operation study will usually precede the drafting of the master schedule, but in custom work this is not always possible. In the latter case times for each operation should be assigned by judgment as closely as possible, subject to rectification when the operation study is completed. The master schedule will thus be either an accurate, or a closely approximate representation of the call of the order on manufacturing capacity.

Incoming orders either may be listed according to their dates of delivery, and taken up for scheduling in that order, or a shop program schedule may be set up in which each order is represented by a line, the length of which will be proportionate to the whole set of operations on the master schedule. Fig. 35 illustrates such a shop program. The date at which each order should be completed and also the date at which the first process should be commenced are disclosed by the chart, which thus indicates the sequence in which each order should be taken up for machine loading assignment.

Relative dates on the master schedule are converted into **actual dates** by application of a calendar scale (Fig. 36). The spacing on this scale must be the same as on that of the master schedule. Only working days are included, so that if the date of delivery on the scale is applied to final assembly on the master schedule, actual calendar dates can be assigned to every step mapped out on the schedule.

Operation studies on orders will be undertaken in the rotation indicated by the shop program schedule. As each study is completed, the preliminary master schedule will be corrected as to operation times, so that machine loading may be carried out on an accurate basis. The way in which jobs are assigned to machines has already been described.

The order, broken down into its ultimate parts or components, has

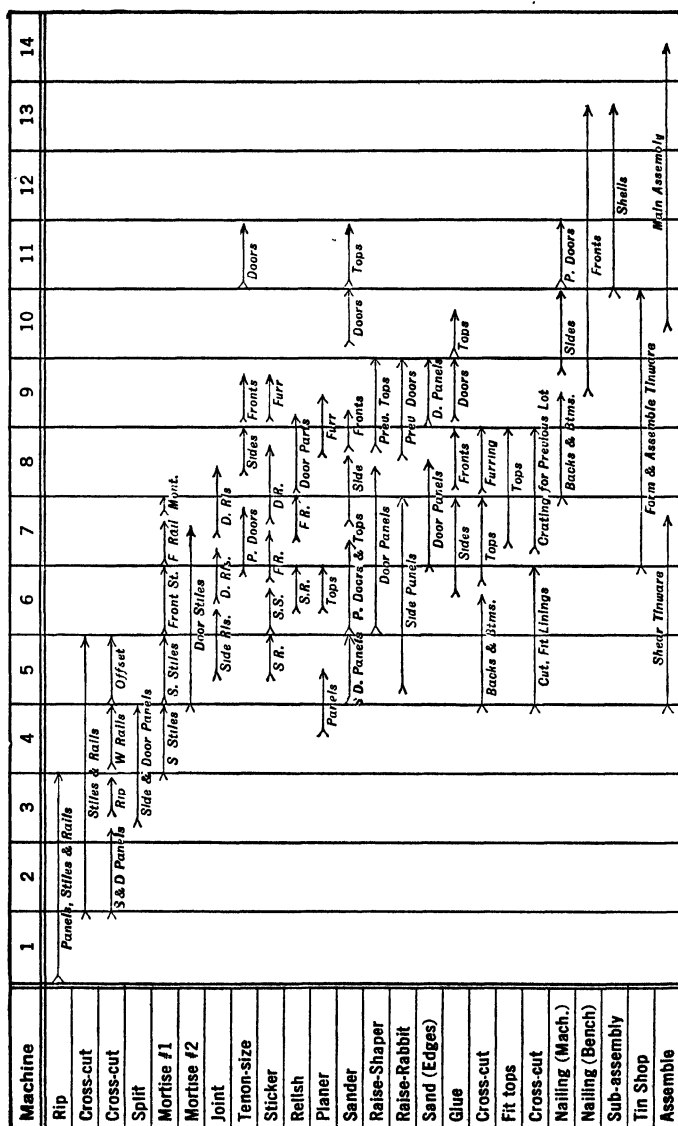



Fig. 34. Graphic Master Schedule for a 30-Doz. Lot of Refrigerators

Corresponding Machine Loading Chart is shown in Fig. 16.

now been incorporated into the stream of production If assignments to machines are carried out as planned, the various parts will be delivered at assembly points and meet in final assembly in time for the promised delivery date to be met. To insure this result, a control mechanism must be set up.

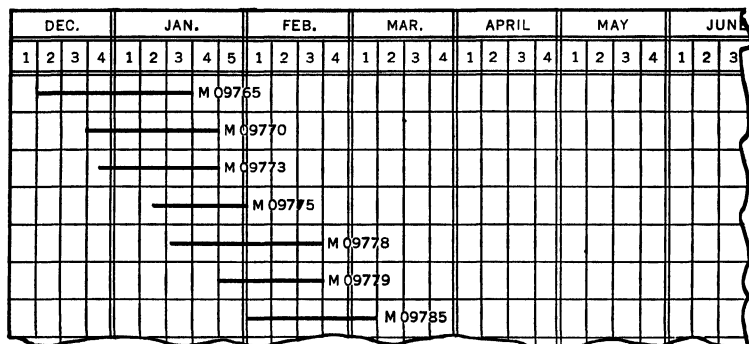



FIG. 35. Shop Program of "Preference of Work" Schedule

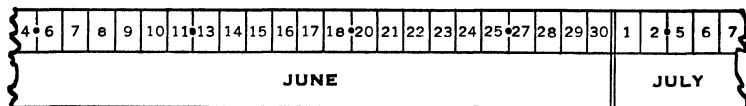



FIG. 36. Calendar Scale for Fig. 35, Shop Program (Sundays and holidays omitted)

CONTROL THROUGH SCHEDULING.—Concurrently with the entry of assigned machine loads on machine load charts, entry is also made on the corresponding route sheet. Against each operation, the machine number, time allowance, and date at which the process should commence and finish are inscribed (Fig. 37). If now route sheets are filed in order of the first date appearing on them, and if each job is marked off as completed, a fair degree of control is obtained. In some plants route sheets are mounted, in order of first date, on swing boards, each board representing a particular future period, which may be a day, week, or month. When the sheet comes into operation, the progress is marked on it, and when the piece is completed the sheet is removed from the board. Sheets remaining on boards previous to the current date are behind time, and call for special attention. For a **small shop** this system should be economical and satisfactory.

More usually progress control is carried out by means of Gantt charts. For this purpose the conventional significance of vertical columns can be extended beyond that of simple time intervals. In Fig. 38 vertical columns represent not only days but also a given output per day, varying from 1,000 to 2,000 pieces. An angle and a figure 1 indicate day on which the first operation is to start (e.g., making of fuse body on September 21). Operations 2, 3, etc., are similarly indicated. When the

final operation has been commenced, output of the complete part commences. and this output is indicated by a thick line extended day by day. In most cases (Fig. 38) this heavy line signifies a daily output of 1,000 pieces, but for some parts 2,000, as shown in the column headed "daily schedule." Angles at the right hand show when the total number of pieces on order should be completed. The thin lines are daily postings of the number finished at each final operation.

In **continuous manufacture**, wherein customers' orders are consolidated into a weekly or monthly total for one kind of product, a Gantt chart like Fig. 39 can be used to control production. In this chart, also, vertical columns represent both time and output at various rates. Planned output per month is shown by figures "2,800," etc., opposite

PART F	*Deliver Mtl. to M60 June 10*				
Op. No.	Operation	Mach. No.	Time Allow'ce	Mach. Assignm'ts From	To
1	*Bending*	*M 60*	*4*	*June 11*	*15*
2	*Punch & Rivet*	*M 81*	*2*	*16*	*17*
3	*Square bolt holes*	*M 31*	*3*	*23*	*25*
4	*Split rings*	*M 93*	*2*	*27*	*28*
5	*Mill lug holes*	*M 90*	*4*	*29*	*July 2*
	To Final Assembly July 5				

Fig. 37. Portion of Route Sheet for Part F (Fig. 21) with Operation Dates Completed

each product. Orders are represented by narrow black lines, production by thick black lines. Open rectangles represent product completed but not yet delivered. Figures "2,800," etc., are tentative and subject to modification if demand falls off for any particular item of product. Extent of commitments ahead for each class is readily seen from the length of the thin black lines. Thus, the current date being assumed as February 18, it can be seen that production of No. 1 coarse ply yarns is sold up to near the middle of August. No. 2 coarse, on the contrary, is sold only a few weeks ahead. In this chart months are divided into fifths, instead of weeks. At a uniform rate of production output figures would therefore vary according to the actual number of working days in the month.

For ordinary **machine-shop work,** where large numbers are not involved, and work is made up mostly of customers' orders, the foregoing types of chart are not very applicable. In all continuous and stock production, the problem is one of controlling a rated output, so many pieces per week or other period. In machine shops and other manufacturing industries not organized for stock production on a large scale, the problem is one of getting separate orders through on time. Such an order may be made up of single parts, or nearly so, as in machine building,

FIG. 38. A Gantt Progress Chart for Control of Operations

This chart shows when work is to be started on each operation, and the progress of work on the last operation for each component part of a fuze.

PROGRESS CHART SHOWING SCHEDULE, ORDERS AND PRODUCTION

(NOTE: If deliveries are ahead of or behind schedule, delivery promises should be advanced or set back accordingly)

ENTERED TO *Feb. 18*, 19 –.

	1922	Jan 21-31	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
SINGLES; #1 Quality		934	2800	3500	2800	2800	3500	2800	2800	3500	2800	2800	3500
#2 Quality		467	1400	1750	1400	1400	1750	1400	1400	1750	1400	1400	1750
#3 Quality		234	700	875	700	700	875	700	700	875	700	875	700
PLY, YARNS; #1 Quality Fine		237	710	888	710	710	888	710	710	888	710	710	888
Medium		380	1140	1425	1140	1140	1425	1140	1140	1425	1140	1140	1425
Coarse		237	710	888	710	710	888	710	710	888	710	710	888
#2 Quality Fine		94	280	350	280	280	350	280	280	350	280	280	350
Medium		377	1130	1413	1130	1130	1413	1130	1130	1413	1130	1130	1413
Coarse		177	530	663	530	530	663	530	530	663	530	530	663
#3 Quality Fine Medium and Coarse		197	590	738	590	590	738	590	590	738	590	590	738
X Grade		267	800	1000	800	800	1000	800	800	1000	800	800	1000

FIG. 39. Control of Output, Orders, and Deliveries (Gantt Chart)

or it may consist of parts made in sets of a dozen or a gross or more, which have to be put through so as to meet in assembly and subassembly at given times. Attention has mostly to be concentrated in getting parts through each single process on schedule time so as to be ready for the next, also on schedule time.

The master schedule (Fig. 21) is representative of this class of production. Fig. 23 is the corresponding machine loading chart, when the sequence of operations is strictly as laid out on the master schedule. Fig. 37 is the corresponding route sheet for part F. To establish graphic control of this order while going through the shops, either a Gantt chart or a control board may be used.

FIG. 40. Gantt Chart Controlling Production of a Single Part

Fig. 40 shows how the progress of part F is controlled on a Gantt chart. Assuming the present date to be July 22 (as indicated by the V at the top of the chart), it will be seen that the first operation on machine 60 is clear; the second operation on M 81 was not completed until the 20th, but all is now clear for operation on M 31 on the 23rd. The upright tick at the left side of the solid lines represents that work has commenced; that at the right side, that the job is completed. The dotted line, which would be in red on the chart, shows that the job is behind time. A vertical rule or rod covering the whole chart is moved forward each day, jobs at the left of this rule being in arrear.

The above arrangements serve where single pieces are in question, as in large machine building. When the product is being put through in lots of a dozen, gross, or other definite number, provision is necessary to insure not only that the operation begins at the right date, but also that a sufficient number of pieces have passed inspection to comply with the order. Alternatively, control of necessary replacement orders must be set up.

Control of the number produced can be effected on the plan used in Fig. 39, the numbers being placed over each process bar to indicate daily production. Failure to reach the standard on any day would mean that the bar must be prolonged (in red) to indicate the time necessary to catch up. Replacement orders would be scheduled like parts, on the

same horizontal line, but distinguished by a different-colored bar or bars.

A system used in manufacturing motors and generators from .5 to 200 hp. at The Imperial Electric Co., where a considerable part of the business is stock production but many orders are for special equipment, employs a control board, of which construction details are given in Fig. 41. Strips of wood are attached by clips to vertical pipes. These strips carry cards on which all the necessary data as to the order, including the routing steps, are inscribed.

The data on one variety of strips are given in Fig. 41. When the planning department is ready to pass an order through the shops, the corresponding stick is clipped on to verticals representing the first manufacturing department. After the work is completed there, the stick is moved on to the sections for subsequent departments, thence to "erecting," "testing," and either "shipping" or "waiting shipping instructions."

Daily reports are received from the shops as to the amount of work completed on each order. These particulars are posted to the card strips in spaces provided. When work is delivered to the next department, the sticks carrying cards are moved accordingly. A separate and somewhat similar system is used in controlling material for orders.

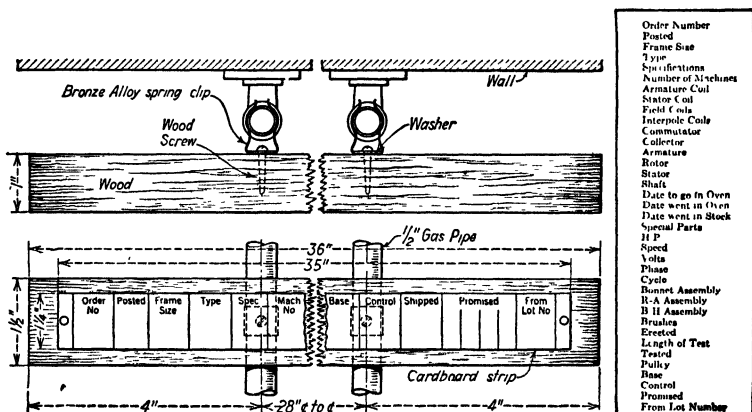



Fig. 41. Construction Details of a Flexible Type of Control Board (At right, data provided for on card strips)

ORDER SCHEDULING.—The order scheduling system used in the Cameron Pump Division of Ingersoll Rand Inc. is typical of similar control systems used by many departments of this organization. Several hundred Index-Visible leaves are used, housed conveniently in ringbooks (Fig. 42). A heading card filed at the top of each leaf identifies the information reported in the columns on each order card.

The cards are 10½ in. long by 1⁹⁄₁₆ in. high, but only the top ¼ in. of each shows when they are nested on the leaf. Any card may be quickly

CAMERON PUMP ORDER SCHEDULE — DATE OF ISSUE — PAGE NO — ORDER STATUS

Priority Status: Cert	Rating	Note	N Y Order No	Date of Order	No of Units	Pump Size & Type	Item No	Customer's Name	Casing Mat'l	Witness Test	Inspection	Delivery Request	Driver Information	F D Y Mat'l	Purch Mat'l	Mach Work Comp't	Assem Comp't	Test Comp't	Eng Status	Bed Mat'l	Bed Status	Shipping Date
WEEK ENDING JULY 10TH																						
3	AA-1		4552	5/10	12	X-10	5	Jeff. Boat	S			7/4	Cent.									
5	AA-1		4661	5/12	18	X-10	3	Kaiser	S	X	X	7/7	Cent.									
3	AA-1		4769	5/14	15	X-10	3	Am. Bridge	S			7/5	Cent.									
3	AA-1		4809	5/16	14	X-10	6	Dravo Corp	S			7/10	Cent.									
6	AA-1		4874	5/11	19	X-10	5	Todd-Bath	S			7/15	Cent.									
5	AA-1		4917	5/20	10	X-10A	1	Rem. Rand	S	X	X	7/7	Cent.									

1ST BILL REC'D ....

2ND BILL REC'D. ....

H P

P O

MAKE..

1ST BILL REC'D ....

2ND BILL REC D ....

H P..........

P O..........

MAKE..........

REMINGTON RAND INC., II PAT NO 1743274 JAN 14 1930

FIG. 42. Visible Index Order Control System

"unbuttoned" from the runway or merely slid up to expose the information below the visible margin.

The week in which the order is scheduled for completion is indicated on a blue card, followed by individual cards showing details of each individual order. These order cards are filed according to delivery sequence. New orders received are filed in proper sequence and any orders displaced from production schedules for that week are moved down to the revised shipping sequence.

Twice a month these leaves are photocopied. Copies are filed in binders for expediters, department foremen, and other interested supervisors and executives. Bound in each book is a cross index of all orders, arranged in order number sequence.

This combination of index flexibility and photography for reproduction greatly facilitates preparation of order schedule reports, with absolute accuracy insured. The status of production of each order is indicated by entry of dates in the squares at the right of the visible margin —these dates forming a visual chart of the progress of each order toward completion.

The objectives aimed at in **progress control** are the same whatever form of mechanism is adopted, namely:

1. That attention shall be drawn to oncoming jobs in time to release orders and take other steps to get them into work.
2. That actual performance shall be recorded, preferably daily, and compared with planned performance, as to (a) due dates, (b) quantity processed.

Designers of control systems sometimes overload them with an unnecessary complexity of symbols and vectors for special indications. "Reason for delay" is one of these. It is probably better practice to eliminate everything from a control board or schedule that does not contribute directly to one or the other of the above objectives. The clearer the story, the more easily it can be read and acted on.

Elements of Dispatching Procedure

DEFINITION.—Dispatching may be defined as

> the routine of setting productive activities in motion, through release of orders and instructions, and in accordance with previously planned times and sequences as embodied in route sheets and loading schedules.

The more complete and accurate the planning, the more dispatching tends toward becoming a mechanical routine.

Principal Factors.—The principal factors or activities included in dispatching are:

1. Movement of material from stores to first process, and from process to process.
2. Issue of tool orders instructing tool department to collect and make ready tools, jigs, and fixtures, and to furnish them to the using department in advance of the time at which the operation will commence.
3. Issue of job orders authorizing operations, in accordance with dates and times previously planned and entered on machine loading charts, route sheets, and progress control sheets or boards.

4. Issue of time tickets, instruction cards, drawings, and any other necessary items to the workers who are to perform the various operations.
5. Issue of inspection orders after each operation to determine the result in numbers of pieces "good" and "bad," and causes of any excessive spoilage.
6. Clean-up on jobs. Collecting time tickets. Recovering blueprints and instruction cards and returning them to production control department. Seeing that work is forwarded to next department, or storeroom or stockroom.
7. Recording time of beginning and completing job and calculating duration Forwarding time tickets to payroll department and records on job to production control department.
8. Recording and reporting idle time of machines and of operators.

Dispatching stations, cages, or offices are the local outposts of planning department, each department of the plant having its own or more than one, if the shop is a very large one.

It has been explained that manufacturing orders form the starting point of a series of subsidiary orders, and that preparation of these working papers should be taken in hand as soon as route sheets have reached the necessary stage of completion. Fig. 43 shows in diagram form the relation of subsidiary orders (1) to operations on a part, (2) to separate parts, (3) to whole order. The routine of dispatching is exhibited in this diagram.

As already explained, the manufacturing order is first broken down into parts and assemblies. Route sheets are then made out for each part and assembly. The route sheets indicate material to be used and operations to be performed and their sequence. Against each operation, its time allowance and the date when it should begin and end, and the tools and fixtures required are entered, and the corresponding blueprint gives data for inspection—limits and tolerances. To give effect to this information, material, tool, job, inspection, and move orders are made out as soon as dates assigned for operations are known. All these working papers are then filed until a day or two before the job should be put into work. They are then issued, released, or distributed by the dispatcher to the various persons concerned. The material will be delivered at the machine, tools and fixtures gotten ready, the operation performed on the material, the pieces inspected, and those which pass inspection moved on to the next process or operation.

An important problem in dispatching is the **filing of working papers** so that they may be instantly found, either for alteration in the program, or for release in ordinary course. As every operation on every part demands several documents, and an order may contain a considerable number of parts, a large accumulation of working papers results. At one time such papers were not made out until the time came to make use of them. This course involved hurry and confusion, probable delay, and certainly much greater risk of error than when, as in modern practice, they are made out in sets, at leisure, and under conditions where attention can be concentrated on the many details they contain. To keep such papers in classified order and to provide for their being released in due sequence and at the right date, special mechanisms have been devised. It is also necessary to establish a sure and quick method of signaling the progress of work in the shops, and the idleness of ma-

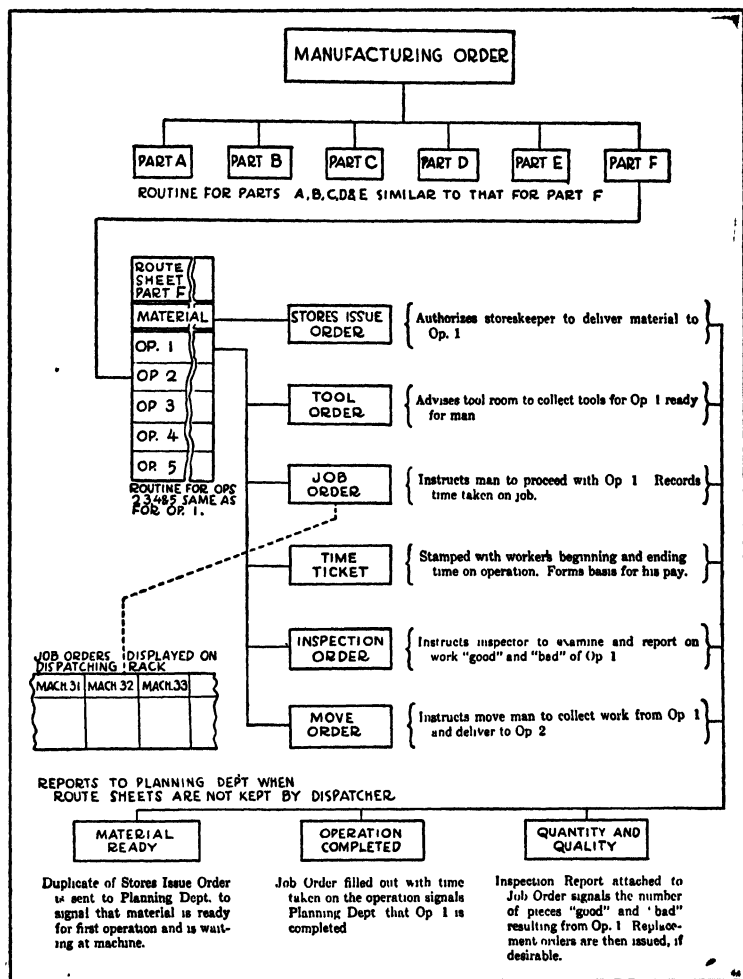



FIG. 43. Sequence of Dispatching Operations

chines, to the planning department, which must also be advised of spoiled or defective work so that replacements can be promptly made.

METHOD OF FILING WORKING PAPERS.—Two main methods are followed in filing working papers.

1. Where route sheets are kept in dispatching cages or offices.
2. Where route sheets are kept in the central planning office.

The first of these methods was that adopted by Taylor. Route sheets were bound up in sets, interleaved with sheets bearing pockets to contain the working papers for each such sheet. The underlying idea was to keep all papers relating to one order together, and permit checking of each paper on the route sheet as and when issued. In practice this method was found somewhat clumsy and inconvenient. It was really putting the duty of progress control on the dispatcher, who usually had plenty of other work to do. Modern practice tends to confine dispatching to the actual handing out and recording of working papers, leaving the control of progress on route sheets and control boards or schedules to be done by the planning department. In this latter case, pneumatic communication between the planning department and various dispatching stations is becoming a frequent practice. For all practical purposes it is equivalent to bringing planning, control, and dispatching into one room and under one control.

Another variant of the dispatching system is used by Bell & Howell Co. Job orders are held in a visible index in the foreman's office. The new order is handed to a workman just before he finishes his current job. On completion of this job he goes to a "substation" near at hand, and makes use of an electric signaling system which transmits symbols to the planning room. He reports the number and the time taken on the old job, and the number of the new job. All entries are made at the planning department end, where as many as three simultaneous changes can be taken care of. It is claimed that this system economizes workmen's time, since as many substations for signaling as required can be provided in convenient locations to prevent delay when reporting. The capacity of the dialing system for signaling information may be gaged from an inspection of Fig. 44, which is the instruction sheet issued for using the system.

When route sheets are kept in the **planning department,** the various orders and working papers are either (1) filed separately in the planning department and sent to dispatchers, one, two, or three days before they should be released, or (2) filed in the dispatcher's cage. In some plants, release of orders is controlled by an **order-of-work list** (Fig. 45) made out daily by the planning department from its loading schedules and route sheets. This list is sent to the foremen of the departments and to their dispatchers, and must not be changed or departed from without authorization.

Orders pertaining to parts can be filed on one of two plans: (1) According to machines. Where machines are arranged in groups and work can be routed to any one of them, then only the group is indexed. Dispatchers assign work to any machine of the group which is vacant. In such cases the route sheet does not specify a particular machine, but

1st – Do not flip or force dial.
2nd – Press red button (ONCE ONLY) to get line.
3rd – Dial symbol letter, Dept. # and check #, Operation # and work station #.
4th – Operator will clear board after information recorded has served purpose.
5th – Dial symbol letter and order number using symbols to fill in spaces 7 and 8 of work form.
6th – Stand by board in case operator flashed "E" or "H" for further information.
7th – If operator dials "H," call your foreman to your station and then dial ALL over again.
8th – If no information is asked for by operator, dial symbol "D" for operator to release board.

Symbols

A – Starting new job
B – Job blocked
C – Job completed
E – Repeat all information (including check #)
G – Group check # on same job
H – Call foreman to your station
J – Job neither complete nor blocked
K –
M – New man
K-11 – Stand by for further information
K-99 – Testing: do not record

Symbols to be Used in Spaces 7 and 8 of Work Form

AA – Subassembly
BB – Part number
CC – Set-up
EE – Special (No.) part #
MA – Main
JC – Job customer
EJ – Expense job

AE – Additional work order
CA or CA plus numbers – Changes on design and construction of tool

FIG. 44. Instruction Sheet for Workman when Dialing as to Progress of a Job

THE IMPERIAL ELECTRIC CO.
PLANNING DEPARTMENT Issued..................19. ...
Order of Work in Dept. No........ ....
SEQUENCE............................ FRAME SIZE .... LOT No........ ....

Mach or Stat No.	Route Tag No Order No	Name of Item	No of Pc's	Pattern No. or Style	Drawing No	Working Sequence	Percentage of Work Done									
							10	20	30	40	50	60	70	80	90	100

NOTE—Foreman must receive through his General Foreman specific authority from Planning Department before any deviation is made from the order of work laid down above.
NOTE—Make out this report in Triplicate for Department Foreman, General Foreman, File. FOR USE IN PLANNING DEPT ONLY

FIG. 45. Order-of-Work Form Controlling Production Sequence

only the group of machines on which the work is to be done. (2) According to order numbers, subdivided into parts or lots. This plan has the disadvantage that it is no guide to sequence, unless it happens, which is rarely the case, that manufacturing orders must be taken up in sequence of their numbers. On the other hand, where an order-of-work list is sent down by the planning department daily, then filing by manufacturing order number is probably the safest and quickest method.

Another method **combines** these **two systems.** Orders are filed under manufacturing numbers, but when advice is received from the stores department that material is ready in the shops, the corresponding operation papers are withdrawn and placed in a file classified by machine numbers. It may be said, in fact, that no uniformity in plan exists. As long as the method adopted permits of instant finding of the papers next in sequence, it is immaterial how they are filed. The method does depend in some degree on the type of production. The more that production tends toward the custom-order-parts-assembly type, the more carefully must the filing of working papers be designed.

ASSIGNMENTS TO MACHINES.—The central feature of the dispatching office is the dispatching board, or dispatching rack. The underlying idea is **visible control.** A certain space is allotted on a wall or board to each machine in the shop. This space is usually subdivided into three compartments:

1. For job actually on machine. A duplicate of the job order actually being worked on occupies this space.
2. For next job in sequence. This space is occupied by a job order and its duplicate which will be transferred to space No. 1 as soon as the current order is completed.
3. For several jobs ahead. Job orders are filed one behind another, as far as possible in the order in which they will later be transferred, first to 2, then finally to 1.

The objective of the **dispatching board** is the detection of shortage or approaching shortage of work for each and any machine. A glance at the board shows: (1) whether all machines are actually engaged on jobs; (2) whether any machine lacks a "next job"; (3) whether each machine has a fair supply of work in reserve after the "next job" has been disposed of. Approaching shortage of work for any machine is reported to the planning department, where it either will be confirmed or, if due to error, will be rectified in time. Opportunity to reroute jobs to idle equipment and relieve pressure on other equipment may also be utilized in some cases.

Methods used to display job orders vary. Taylor used double hooks, order or operation slips being punched to correspond and hung on these hooks. Modern practice tends to use pockets, much after the style of time recorder racks, which are so familiar as not to need description. Orders do not require punching, and are more easily handled by this method. Display racks may be made of wood or metal, and three subdivisions may be placed side by side, or in front of one another on successively lower levels. The principal consideration is to preserve visibility, so that a single glance can take in the whole series, and detect any machine where a shortage of work is threatening.

LOCATION OF DISPATCHING STATIONS.—Only in very small plants is it possible to center work at a single dispatching station. In larger plants one for each department is the usual minimum, otherwise too much time is taken up in walking to and from the station when changing jobs. Where pneumatic tubes are used to connect with the planning department, no difficulty arises from this subdivision of the dispatching function. An alternative is to rely on the plant messenger service to collect completed orders and convey them to the planning men, but where route sheets and control boards are located in the planning room this latter method implies delay between completion of the job and its being noted on route sheets or control boards. Direct messenger service may be used, but it is expensive. In some cases where physical layout permits, mechanical carriers, less costly than pneumatic tubes, have been used with success.

ROUTINE OF DISPATCHING.—The routine exhibited in Fig. 43 may now be described, step by step. Preparatory steps are: (1) getting material to the place where the first operation is to be performed; (2) getting tools, jigs, and fixtures to be used on the first operation collected together and ready for issue to the workmen.

Materials.—Two different methods of initiating the movement of material are in use. In some plants a stores-issue order, made out at the same time as the corresponding route sheet, and marked with the date at which it should be delivered to the shop, is filed with the storeskeeper in a tickler in order of due date. When this date arrives, the material is sent into the shop, and a duplicate of the issue order is forwarded to the planning department and thence to the dispatcher to signal its arrival. Another method is to file a duplicate stores-issue order with the other working papers pertaining to the part, and to hand it with these papers to the dispatcher for release at the appointed time. This time will be a day before the operation is to commence. The storeskeeper prepares the material ready for issue, but does not actually move it into the shop before getting authority to do so.

Of these two methods, the last is more flexible. It permits of a change of program down to the last minute. Should the operation be canceled or the routing changed, the alteration can be made on the stores-issue order, or it may be held up, without having to pick it out of the storeskeeper's files. The choice between these methods will depend much on the nature of work. In stock production the former practice may serve, while in custom manufacturing, with its comparatively disturbed routine, the latter plan may be preferred. The essential point is to get the material where it is needed, neither too early nor too late for the operation.

Tools.—In all machine-shop and similar work, it is the practice to specify cutting tools for the job, as well as to list all jigs, fixtures, gages, etc., which will be required. These particulars are listed in a "tool order" of which a specimen is given in Fig. 46, as used in a plant making small machines. A tool order is prepared from the operation study sheets at the time of making out the route sheets and is filed with the other working papers until wanted. As soon as the material is in place, the tool order is released. The toolroom collects the tools and holds

TOOL ORDER DATE 3-8

NO. REQ'D	TOOLS AND GAGES	SECT	BIN	NO. REQ'D	TOOLS AND GAGES	SECT	BIN
1	Set of 18-38 Vise Jaws VF160	1C	28	1	x-467	6A	28
1	3" dia x 7/16" face x 1" hole			1	7/16" Plug Gage		
	Side Milling Cutter						
1	#50 Vise	1E	54				
1	1" Dia. Arbor.	Rack					
				1	Drwg E-97		

NAME	OPER.
Rocker Arm for Operating Distributing Roll	Mill inner surface in vise jaws.

PART NO	OPER. NO	DEPT.	MACH	EQUIP NO
18-33	6	4	Hand Miller	981

FIG. 46. Tool Order

them until asked for by the man on the operation specified. Authority is given by presentation of the job order or time ticket for the operation in question.

Job Orders.—Materials and tools now being provided for, the operation itself may proceed at the scheduled time. Authority to proceed with the work is given by release of a "job order," which serves to identify the work to be done. The amount of detail on job orders varies greatly. In some cases, particularly in repair work, the job is described in as much detail as necessary, but ordinarily actual instructions are obtained from blueprints and instruction cards, whether these are retained by the foreman and verbally explained to the workman, or handed to the latter. Under such circumstances, data on the job order are merely such as will assist in the routine. The usual information included comprises:

1. Order number. Part number or symbol.
2. Operation and operation number.
3. Machine and man number.
4. Number of pieces to be processed.
5. Date at which job should start.
6. Time allowed for operation. Price if any.
7. Space for recording starting, finishing, and elapsed time on the job.

Job orders are made out at the same time as the route sheets. If assigned to machines of which there are several alike (group of machines), only the assignment to the group should be made in the first instance. The actual machine should then be assigned by the dispatcher at time of release of the order.

Combinations of job orders with other forms are often used. Inspection reports are sometimes provided for on the reverse side. Move coupons are often attached. Sometimes the job order is used as a time record and sometimes this latter is separate. Fig. 47 shows a job order combined with a tabulating card, which when punched is used for costing, payroll, and for other purposes. Fig. 48 shows a job order, here termed a "production card," as used in a large plant manufacturing automobile bodies. The job order itself is duplicated, one copy, as already explained, being kept in the dispatching rack. The lower portion of the form is an inspector's report, provision being made for half-hourly inspection checks.

CLOCK NO | NAME | SHOP ORDER | PRODUCTIVE LABOR TICKET

GOOD PCS | SCRAP PCS | OPERATION NO

190-1100 99999-23456
1M 4
7D 2 .69 .12 4.07 4.52
7D 1 .32 .10 1.52 1.767
7D 3 .11 4.55 5.05

ICM 726742 MS | LICENSED FOR USE UNDER PATENT 1 772 497

OK D BY | O T HRS | TIME HRS

TOTAL GOOD PCS | TOTAL SCRAP PCS | X WAGES D W LOSS | BURDEN

ELAPSED TIME | TOTAL PCS FIN | JOB WAGES | SET UP & O T

STATUS OF JOB

Fig. 47. Job Order Tabulating Card

Routine as to job orders is simple. On release, the order is time-stamped and handed to the workman, who uses it as an authority to collect his tools and fixtures for the job. When the job is completed the job order is again presented at the dispatching office, where it is time-stamped again, and a new job order handed to the workman. The original and the duplicate of the completed job order are then forwarded to the planning department and to the cost and payroll offices for use in making entries in their records.

Job Dispatcher Control.—In the Warner & Swasey Co. job dispatcher control is maintained by means of Kardex panels placed beside the time clock on the desk of each departmental job dispatcher. Visible index inserts are placed in the pockets of the panels showing workers' numbers and names at the left. Tabulating system time cards are used for jobs, and the dispatcher assigns work to each operator by filing time cards behind his insert. As each job is completed, the worker comes to the desk, takes his next time card from the file, and stamps it at the time clock. When the work is done he returns the card to the dispatcher's desk. The visible index insert does not extend entirely across the pocket and thus the bottom of the time ticket is exposed to view with the blank starting time space showing. When no cards are filed under a worker's number and name, the dispatcher knows

1A-5

PRODUCTION CARD 168

Pc No 60130-RH Die No. 9975

Name Rear Door Inside Panel Trips

Oper. 1st Form Pocket

Qty. Req 2000 R.H. Company X Tour

Date	Mch No	Man No	Scrap	Clock Start	Clock Total	Actual Count

DELIVER ______ TOTAL

TO ______

INSPECTOR'S REPORT

Repairs or alterations required to improve stampings

If necessary send stamping to Machine Shop Clerk.
Can additional stamping be passed in present condition?

INSPECTOR'S HALF-HOURLY CHECK

Day	7	7 30	8	8 30	9	9 30	10	10 30	11	11 30	12	12 30	1	1 30	2	2 30	3	3 30	4	4 30	5	5 30	6	6 30
Night	7	7 30	8	8 30	9	9 30	10	10 30	11	11 30	12	12 30	1	1 30	2	2 30	3	3 30	4	4 30	5	5 30	6	6 30

FIG. 48. Job Order Combined with Inspection Report

that a job must be prepared for the man to utilize the full productive time of each employee.

Specification Control.—The record system shown in Fig. 49 is used by the Central Metallurgy Department of the Carnegie Illinois Steel Corp. in production control for checking to determine the disposal of each heat produced in the company's many mills. More than 10,000 customer specification cards are indexed in the record system, in groups by types of steel. Check marks in the squares at the right of the visible margin on each card show the carbon and manganese content listed in that particular specification.

As each heat is processed through the furnaces at the mills, the necessary test analyses are made and the information obtained is forwarded by direct wire connection to the Central Metallurgy Department. Here, within a two-minute period, chemists check the visible margins of the record cards to ascertain how closely the heat meets one or more

Fig. 49. Record System for Specific Control

PART NO SIZE OR TYPE
NAME — DESCRIPTION
LOCATION
ACCT NO
DWG NO
MATERIAL REQUIRED PER
(PIECES)
FT
LBS
MONTHLY DISBURSEMENTS

NO	19	19	19	19	19
JAN					
FEB					
MAR					
APR					
MAY					
JUN					
JUL					
AUG					
SEP					
OCT					
NOV					
DEC					
TOTAL					
INV					
UNIT COST					
PRICE					

CASTING
FORGING
STAMPING
BAR STOCK
PURCHASED
MATERIAL-SPECIFICATIONS

VENDORS
1
2
3
4
5
MIN MFG OR PUR QUAN
FOR DEPT NO MIN

SUB ASSEM		COMPLETE ASSEMBLIES			
MODEL	NO	MODEL	NO	MODEL	NO

REQ DATE	CLEVE		BALANCES		ORDERED										RECEIVED		NET PER UNIT		INVENTORY COST	
	SUB	COMPT	PHY	SHORT	DATE	QUAN	AUTH P	F	E	S	VEN	P O NO	✓	DUE DATE	DATE	QUAN	LABOR	MATERIAL	TOTAL	UNIT

FIG. 50. Control Over Parts Manufacturing and Costs

B 111
KEY
CUSTOMER
MATERIAL
PART NO
DESCRIPTION
KEY
PLAN NO
CUST ORD NO
QUANTITY
DATE ORDER
DEL SPEC
DATE
AMOUNT
TOTAL

Fig. 51. Work-in-Progress Record for Parts Production

customer specifications on file. The test figures must be checked in this way to reach a decision as to whether the heat should be completed, altered, or scrapped. Signals (not shown) set over the 1 to 4 numbers on the bottom of the cards indicate the quarter of the year in which the specification was last ordered by the customer, which is an indication determining whether orders are likely to be received in the near future so that the steel being processed may be utilized. Decisions are made on the basis of the actual data visibly charted by this record, and thousands of dollars in cost often hinge on the speed and accuracy of the decision rendered. The Metallurgy Department estimates that this record, with its visual controls, pays back its entire cost each week in savings made in production costs.

Parts Manufacture and Cost Control.—A control over parts manufactured in the Cleveland Pneumatic Tool Company is maintained by the Kardex system illustrated in Fig. 50. The upper card provides specifications, a summary of disbursements, and space for entering production orders placed and quantities received on them. It also serves as the requisition when the item is to be reordered. The lower card records issues and balances.

The costing plan is an interesting feature of the record. Each production run is costed and each item issued is priced at the cost of the run from which it was made. Therefore, receipts from production are not immediately entered on the lower card, but are held back until the previous lot is exhausted. Then the quantity from the oldest run not yet recorded on this lower card is brought down to the balances column, together with its unit cost. To secure the total quantity actually on hand it is necessary to add to the latest figure on the lower card any quantities not yet brought down from the received section on the upper card.

A copy of the production order is kept in the pocket and as labor and material costs are received, they are posted to the production order. When the job is completed, a recap is made of this cost information to the upper card, and the production order is removed. The Graph-A-Matic movable signal at the bottom of the lower card indicates Normal, Requisitioned, Order No. Request Made, Ordered, Rush Order, and if overstocked, the number of months' supply on hand. The ¼-in. movable signal at the left shows the month when the item was ordered.

A work in progress record maintained at the Thompson Aircraft Product Co. (Fig. 51) accumulates orders for each specific part on a Kardex card shown at the top of the accompanying illustration. As production is released to the factory, progress is recorded on the lower set of forms. Tabbed overriding cards, shown in the diagram, provide space for keeping track of the job through 20 separate operations, showing the quantity in process at each stage until the work is completed. Shipments are recorded in the column at the right. When rush deliveries of any part are necessary, the group can be located and operations can be rescheduled to meet the customer's delivery requirements.

Progress of Work.—The record used by the Briggs Clarifier Company and shown in Fig. 52 is a basic instrument of production control, because it charts the progress of an order through receipt to completion. Orders in most plants follow a definite flow-line of procedures and in

Fig. 52. Record to Control Work from Start to Completion

this record the key points are printed on the form. The record is indexed alphabetically by customer's name, which appears on the visible margin along with the estimate and job order numbers. A ¼-in. colored transparent movable signal over the left-hand 1 to 31 scale shows the date on which the current step is scheduled for completion. A glance down the slides each day spots any signals lagging behind the current date—thus prompting attention. The Graph-A-Matic movable signal at the right shows by number the current step—thus revealing the present status of the order.

Inspection and Release of Work.—Two further steps have to be taken by the dispatcher before the job is disposed of. Inspection must be arranged for unless it is being carried on continuously, and completed work must be moved to the next operation. Instruction forms for this purpose are frequently combined (see Fig. 48). Inspection orders are so arranged as to specify: (1) order and part, (2) operation, (3) man's number for identification purposes. Spaces are also provided for the report, which must indicate: (1) number of pieces good, (2) number bad, (3) number capable of repair. Move orders are sometimes separate slips, but more usually take the form of additional lines at the foot of the job order or inspection order. In Fig. 48 the words "deliver to" on the upper part of the form are moving instructions. Inspection and move orders are time-stamped on their return to the dispatcher and are then sent in to the planning department for entry on route sheets and control boards. The question of replacing parts that are defective and have failed to pass inspection is also taken up by the latter department. **Replacement orders** are issued when the shortage is greater than the allowance made for this purpose in economic lot sizes, or excess quantity found defective, according to conditions.

Work Behind Schedule.—The regular routine of dispatching ends with methods of control similar to those just discussed as regards individual operations. It is simply repeated in all details for the next operation. Exceptions to routine must be taken care of, particularly as to lots behind schedule, and idle machines.

Lots behind schedule are listed each day by the planning department, and copies are sent to dispatchers and the foremen concerned. Job orders for such parts or lots are to be distinguished by a colored sticker, signifying that they are to receive precedence over other lots where possible. It is sometimes the practice to affix a brightly colored tag to the work itself. The general idea is to so call attention to the delayed part that it cannot fail to receive preferential treatment. In large plants, where a considerable number of parts are going through at one time, and delays are of daily occurrence, it is the practice to employ a "tracer" attached to the planning department, whose duty it is to keep in touch with all delayed work, and insure its being handled with all possible dispatch.

Idle Machines.—Idle machines are a considerable problem in many plants. Speeding up of machine output, unless accompanied by increased sales, creates a surplus machine capacity in itself. Idle machine time is especially noticeable with automatic equipment and short-cycle machines. Automatic screw machinery, rivet-making machines, double-head surfacers, automatic drilling machines, and many others, unless loaded

with a constant flow of work, represent a considerable investment and burden which is amplified per unit of product by a low "in operation" time. Absence of skilled operators is also a factor contributing to idle time, and is often due to irregular machine loading, peaks of which require additional men. From all points of view, therefore, idle machine time must be closely watched, so that appropriate remedies may be worked out.

Whenever a machine lacks work, an **idle machine report** similar to Fig. 53 is made out. This report can usually be filled out in advance of actual idleness when the reason is lack of work. Breakdowns can be reported only as they occur, and should be treated as urgent. Information should be given to the planning department immediately so that rerouting of work, if possible, can be effected. Data should include: (1) machine number, man's number; (2) the hour when idleness commenced or will commence; (3) reason for idleness. On receipt of this report the planning department will make entries on route sheets and machine loading and progress charts, and will take such steps as are possible to rectify the condition. A good example of an "interruption report," as used in the plants of a large company making shipping boxes, is illustrated in Fig. 54.

Dept. No. | IDLE MACHINE CARD | Machine No.

Date | MACHINE DESCRIPTION | Hours Idle | Shift 1 2 3

No. Operator | No. Material | Out of Order | Awaiting Instructions | REMARKS

No. Orders | Defective Material | No Power | Misc.

6.30 15 6 45 30 15 5 45 30 15 4 3.45

All cards must be sent in each day to Efficiency Department to be recorded and filed.

6.30 45 7 15 30 45 8 15 30 45 9 15 30 45 10 15 30 45 11 15 30 45 12 15 30 45 1 15 30 45 2 15 30 45 3 15 30

FIG. 53. Form for Reporting Idle Machines

Causes of idleness, particularly when work is actually available, should be carefully charted and studied by the planning department. Fig. 55 represents a study of this kind undertaken on a battery of 46 automatic screw machines of several sizes and types. Causes were classified. Where breakdowns appeared frequent, overhauling of the machine, with periodic inspections and strengthened repair service improved this condition. Defective material as a cause of stoppage was rectified by cooperation with the purchasing and inspection departments. Rerouting and diversion of work from hand screw machines to automatics provided

REPORT ON INTERRUPTIONS

RECEIVED

REPORT ANY DELAY HOLDING UP PROGRESS OF WORK, WAITING TIME AFFECTING BONUS OPERATORS, DAMAGE TO MATERIALS, MACHINE REPAIRS, OR CHANGES.

MONTH DAY YEAR

SCHEDULE MAN

PROGRESS OF WORK ON ORDER No.

NOW IN OPERATION AT

IS HELD UP BECAUSE OF

DELAY

CHANGE

WAITING

REPAIRS

DAMAGE, IF ANY

CAUSE

REMARKS:

EMPLOYE'S NAME No.

OPERATION

REPORTED BY

INSPECTOR IN CHARGE

CHIEF INSPECTOR

PRODUCTION MANAGER	SCHEDULE MAN	ROUTE MAN	PAY ROLL MAN	SUPERINTENDENT	

Fig. 54. Form for Report of Interruptions

a more even flow of jobs. Results of the investigation were charted as in Fig. 55. By making improvements in the control procedure, idle time amounting to 6,340 machine-hours per year was eliminated, equal to 5⅓% of the machine time of the entire battery. The method of summarizing idle machine time, both as to quantity and value, is given in Fig. 24.

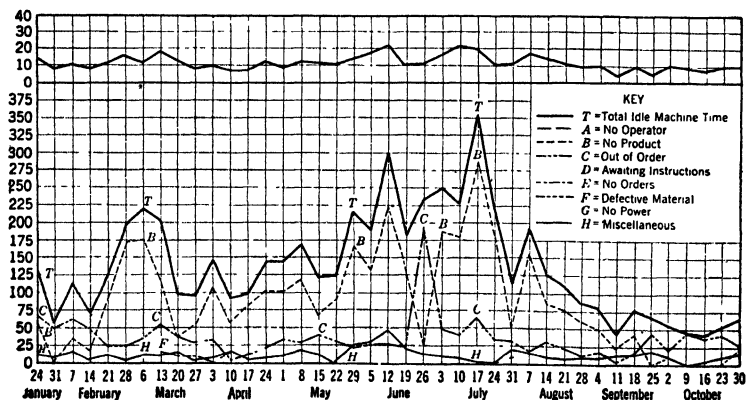



Fig. 55. Study of Causes of Idleness on a Battery of Automatics

MACHINE ACCOUNTING APPLIED TO PRODUCTION CONTROL.—Two general applications of machine methods in production control systems have been made. The one avoids the danger of error in copying identifying symbols, descriptions, and essential information that must be duplicated on forms and in paper transaction, by providing means to print or reproduce these data quickly and accurately by means of plates or duplicating machines. The other applies machine accounting methods to the records in a factory production control system. Production planning, routing, scheduling, dispatching, and inspection records are kept on punched cards, and from these records the movement of materials, performance of machines, and operation of labor are directed and checked. Statements as to the status of a production program at any time, and the end result of a program that is completed are regularly developed and compiled from such cards.

SECTION 3

PRODUCTION CONTROL SYSTEMS

CONTENTS

Gantt Charts

Punched-Card and Tabulating Systems

Duplicating and Communication Equipment Systems

SECTION 3

PRODUCTION CONTROL SYSTEMS

OBJECTIVES OF PLANNING AND CONTROL.—The objective of production planning is to prepare the way for, and facilitate the carrying out of, programs of manufacturing on an efficient, properly timed, well-coordinated, and low-cost basis, so as to complete the required amount of satisfactory finished product on scheduled delivery dates. Planning, however, is futile unless the means are set up to apply the plans and do the work in the manner and time decided upon. Checks and controls of a suitable kind are necessary for this purpose, but adequate facilities must also be provided or else the program cannot be carried through as conceived and laid out. It is important, therefore, to set up an effective system of production control, adapted to the nature of work, method of manufacturing, and size of plant, so that regular channels of work flow and standard procedures may be available to prevent interruptions, clear up delays, and keep production moving.

IMPORTANCE OF A SIMPLE WORKABLE SYSTEM.—Production control systems, organized and operated with proper provisions for carrying on the fundamental functions and activities of production planning and control, will accomplish such purposes at the least cost and with maximum results. Such systems must be carefully thought out before an attempt is made to set them up. A mere assembling of separate devices and routines used in different plants, even those in the same kind of industry, will not necessarily build up a good control system. The "what, why, where, when, and how" of the various steps and methods require determination. Forms are important parts of the system but should not be too numerous, too detailed, nor too complicated. Whenever possible one mechanism or one form should be used for several purposes. Wherever procedures and paper work can be omitted, short-cut, or streamlined and still bring about the desired results, such simplification is to be recommended. System need not degenerate into useless work and "red tape."

It is evident that the greater the number of elements involved, the more difficult is the problem of systematizing and controlling them. The value and importance of a production control system increases in proportion to the number of elements to be checked and coordinated.

Procedure in a Production Control System

PLANNING IN ADVANCE.—Production control is secured by carefully planning in advance every operation and every movement necessary to the manufacture of the final product. Preplanning involves accurate knowledge of:

1. Economic manufacturing or purchasing quantities.
2. Standards of specification.
3. Special tools required.
4. Features standards.
5. Kind and quantity of material required for the product.
6. Time required to obtain raw material.
7. Methods of performing operations required in manufacture.
8. Productive capacity of equipment.
9. Time required for each operation on the product.
10. Limits of quality necessary in manufacturing.

All of the above activities must be coordinated to form a **logical and definite sequence of operations** to accomplish a definite object at a definite time. The nature of control will vary with the industry. Manufacturing, for the purposes of production control, may be divided into the following classes:

1. One order for one piece or product; the piece or product never to be reproduced.
2. One order for several pieces or products; the products never to be reproduced.
3. Repeat orders at irregular intervals for one or few pieces or products.
4. Repeat orders at irregular intervals for many pieces or products.
5. Repeat orders at uniform intervals for one or few pieces or products.
6. Repeat orders at uniform intervals for many pieces or products.
7. Continuous or standing orders for the same piece or product.

Any industry may have any combination of two or more of these classes. In analysis for production control, this situation should be recognized. Work may be grouped into the above classes and a control plan devised to secure the best results for each class.

Factors to Be Taken Into Account.—The major factors entering into production control are:

1. Analysis of product.
2. Control of material.
3. Definite routing for every item or product.
4. Scheduling of work through the factory.
5. Dispatching work to various operations.
6. Timekeeping.
7. Inspection.
8. Cost analysis.

The minor factors, affecting in considerable degree the major factors listed above, are:

1. Arrangement of productive equipment in the factory.
2. Standardization of equipment.
3. Standardization of operations.
4. Revision of special tools, jigs, and fixtures.
5. Development of an adequate tool supply.

In this Section discussion will be restricted principally to coordinated procedures involved in systems to control the routing, scheduling, and dispatching factors.

Routing

FACTORS IN ROUTING.—There are many factors involved in routing as a function of production control.

1. A study of the product to determine the possible methods of making it and to decide on the best method.
2. Study of methods to determine what, if any, special equipment is necessary to carry them out.
3. Analysis of machines and equipment available for doing the work to determine their capacity.
4. Laying down of the sequence of operations.
5. Decision as to speed at which operations shall be performed.
6. Determination of time required for each operation. The factors covered include machine set-up time, machine operating time, allowances for process operations (heat-treating, metal finishing, etc.), bench-work time, inspection time, and time consumed in handling and transporting work in process.
7. Preparation of route sheets or listing of the sequence of operations. It is often desirable to incorporate on such route sheets detailed information regarding some of the decisions arrived at under factors 1 to 5.
8. Grouping of route sheets into subassemblies and major assemblies to insure that components of final product which should be processed at the time will be started in process at such times as will insure their being completed together.
9. Preparation of work orders for the purpose of carrying into effect the details of routing.
10. Adapting procedures to the dispatching system in use—centralized or decentralized.

METHODS OF WORK.—Several methods of accomplishing the desired results are usually available in manufacturing, particularly in any of the first four classes of manufacturing listed on page 168. As an example, in machine-shop practice many turning operations may be performed in a lathe or boring mill. Flat surfaces may be machined on planers, milling machines, Kellers shapers, slotters, and other machine tools. In paper box manufacturing, boxes may be made either by hand, by several machines, each requiring an operator, or by an automatic machine which performs most of the functions of box making. In foundry work molds may be made by machine or by hand at the bench. Several castings of the same type may be made in a single flask or one casting may be made per flask.

Each component of a manufactured product should be subjected to analysis which will determine the best method to use for each operation. Such an analysis takes into account the **factors of relative times** required by the different methods; degree of accuracy desired, and the readiness with which accuracy can be secured; relative amount of equipment available for one method or another; the relative skill required by the several methods; greater possibility of spoilage or defective work by one method as compared with another. Another factor of importance is whether special tools, jigs, fixtures, or equipment will be necessary with a particular method. The methods decided upon in many cases are recorded on shop instruction cards.

Quantity of product to be made also must be considered. For example, a study of several methods available for performing a certain

machine-shop job might indicate that the most economical method from the standpoint of time consumed would be by milling. To do the job properly, however, might require building special fixtures for holding the work. An alternative method would be planing. Planing time might be double milling time. However, if the number of pieces to be made was not sufficiently large to absorb the cost of fixtures and still show an economy over the saving in time by milling rather than by planing, the latter would be regarded as the proper method of doing the work.

Special **tool, jig, and fixture design** should receive attention, especially in machine-shop work. Operations that may be difficult, costly, or even impossible to perform by ordinary methods, frequently can be done with great facility by means of special equipment. Furthermore, by means of special tools, jigs, or fixtures, standard machines may be adapted to the same work as special, single-purpose machines. In the design of such auxiliary equipment, the following considerations should be given attention: the fixture should be readily mounted upon and removed from machines; it should so hold the work or tool that the highest degree of accuracy consistent with the job will be obtained; it should be possible to mount the work or tool in the fixture with the minimum of manipulation; the fixture or tool should be practically foolproof and easy of cleaning, inspection, repair, and adjustment; it should show such marked saving of time, or greater precision of work, as compared with ordinary methods as to leave no doubt of its desirability.

MACHINE ANALYSIS.—Machine analysis is a necessary prerequisite to routing, for the reason that, unless the capacity of each machine concerned in production is accurately known, there can be no intelligent preplanning. The time element is the vital factor in preplanning. The time required for operation is so closely linked with machine capacity that, unless the latter is accurately known, the time required for the operation on the product cannot be fixed.

Machine analysis depends upon the character of machines, kind of work to be done, and nature of material. Thus machine-shop practice and the ability of machines to take heavy cuts depends upon rigidity. method of mounting cutting tools, and amount of power that can be delivered to it. Heavy cuts and extreme accuracy cannot be expected from a boring cutter, mounted on the extreme end of a boring bar and unsupported at that end. Capacity also depends upon the shape of cutting tools and the speed and feed at which they can be operated. If the machine is so geared as to render unavailable the best combination of speed and feed demanded by the work, the next lower combination must be used and the capacity of the machine on that particular work is thereby diminished. The nature of material is important. It is obvious that hard steel cannot be machined with the same rapidity as soft cast iron. The purpose of machine analysis is to give information regarding the capacity of the machine under various conditions.

Similarly, in other classes of manufacturing, conditions of work are affected by considerations outside of equipment. The speed of operations of box-making machinery is affected by the character and thickness of the strawboard used. In textile work the highest speed of operation is impossible with certain kinds of yarn and classes of fabric. A detailed machine analysis in these cases will show the maximum capac-

ity for the various conditions that may be encountered in the usual run of work.

Thus, on a given lathe job, the **best cutting speed** to be used is determined by the nature of the material. Circumference of work divided into best cutting speed gives required revolutions per minute. Speeds available in revolutions per minute are shown on the analysis. The nearest speed to that desired is selected. The feed that can be used depends upon the nature of the material and the speed. From a chart, table, or slide rule, the best feed corresponding to the selected speed can be determined. The closest feed available in the machine to this ideal feed is designated as the one to be used. This analysis gives the closest approach possible to the ideal performance of a job. From information so derived, and from the dimensions of the work, it is a simple matter to calculate the time required for machining. Time so calculated is more accurate than shop estimates and can be used safely as a basis for routing and scheduling in production control.

In plants operating a large number of similar machines, it is usually desirable that all machines employed for the same purpose be of the same capacity. Thus, in a group of 30-in. engine lathes it is important that the same speeds and feeds be available on all. It is then possible to route work to a group rather than to the individual machine. This situation simplifies both routing and dispatching of work. Where machine analysis shows the capacity of equipment of the same class to vary from machine to machine, it usually is wise to make such alterations in equipment as to give all units in the particular class the same capacity, to the extent that this can be done practically.

SEQUENCE OF OPERATIONS.—Routing really begins at the determination of the sequence of operations. Methods of work and machine analysis are preliminary thereto. Routing can properly be performed only by some person who is thoroughly familiar with the character of the work to be done and with the processes for doing it. The sequence of operations adopted for any class of work may have a noticeable effect upon the time and cost of production. Changing the position of a single operation in the sequence often may facilitate the performance of all other operations on the part. Thus, in a certain class of paper box manufacture, where the box has a printed design, the ordinary practice is to print upon large sheets of strawboard which are later cut into pieces of required size and shape to form individual boxes. Certain conditions may arise, however, to make it advisable first to cut the sheet and afterwards print it.

Another example is from machine-shop practice. In a certain piece a number of surfaces may be located at different distances from the center of a drilled hole. It is of importance to determine whether the hole shall be drilled first and surfaces finished in relation thereto, or whether the surfaces shall be finished and the hole located with reference to them. In the first method a plug might be dropped into the hole and the surfaces located from it by means of gages or distance pieces; in the second method, if the surfaces are first machined, the piece may be put in a drilling jig which will locate the hole. If the piece is to be made in a quantity sufficient to warrant expense of constructing the jig, the second method will probably prove more accurate and cheaper.

MASTER ROUTE SHEETS.—When the sequence of operations has been determined, this sequence should be made a permanent record by listing it on a master route sheet (sometimes called "operation sheet"). The master route sheet should list every separate operation to be performed. If a special adjustment of a machine is to be made for an operation, or if special tools or fixtures must be placed on the machine, each of these factors should be listed as an operation. The time required for each of these operations will then be listed opposite the operation, together with the machine or workplace at which the operations are performed. Time should be stated in hours or minutes for single piece, except time for set-ups or adjustments, which should be counted as a total time for each job, lot, or group of pieces. The reason for this practice is that operations are repeated for each piece in each lot, while set-up or adjustment is made once for a lot.

Exception to this practice of separating set-up or adjustment time from operation times may be made when work is put through in standard lots which do not vary in size. Set-up or adjustment time may then be divided by the number of pieces in the lot, and the time thus found entered on the master route sheet as time per piece. Multiplying time per piece by number of pieces in the lot and adding set-up or adjustment time (sometimes called preparation time) gives the time required per lot for each operation. This procedure furnishes a basis for ascertaining when actual production work should be started. To the time required for each operation is added time necessary for movement of materials between operations. Usually, where the work is not conveyorized, it is advisable to allow one day between successive operations for this purpose, especially when the work passes from one department to another. Where materials handling is scheduled, the time can be reduced to hours or minutes.

In certain classes of manufacturing, particularly those involving subassemblies and major assemblies, it is the usual practice to deliver the various parts to a storeroom commonly designated "worked-material stores" or "finished-parts storeroom." It is advisable to indicate for each operation on the master route sheet how many working days ahead of the time when the parts are due in worked-material stores the work should be started. A master route sheet carries complete information regarding lot size, material, machines upon which various operations are performed, and the location of these machines in the shop. Such a sheet later becomes the basis of the schedule which governs movement of the work through the shop.

INSTRUCTION CARDS.—The time taken for each operation as set down on master route sheet should be determined by detailed analysis of operation itself. This analysis should include every item and movement of workmen or machine involved in performance of the operation. Apparently insignificant details should be included, as changing man's job ticket, his return to work, placing work in and removing from machine, setting up tools and equipment. For those operations involving action by the machine, details of rate at which they should be operated should be included. For machine tools these include speed and feed. Amount of material to be removed should be given where such information is necessary; that is, depth of cut for the feed and speed are figured. In many cases the latter information is unnecessary;

for illustration, where castings and forgings have a definite allowance for finishing, and work can easily be done with one roughing and one finishing cut.

Specifications which may be given on instruction cards in other industries are speed of looms and spinning frames in the textile industry, length of time that rubber should be calendered in the rubber industry, speeds of cutting and gluing machinery in the paper box industry, etc. The purpose is to give all the information necessary to enable the time element of machine operation to be determined. Feeds and speeds in machine-shop practice may be obtained from tabulated data such as that in the A.S.M.E. Manual on Metal Cutting, that in the bulletins of the Manufacturing Engineering Committee of the A.S.M.E., and later work which has been done by engineering committees, by Professor Boston at the University of Michigan, etc.; and by means of special slide rules.

The time required for other items on instruction cards may be obtained in several ways: by time study, by records of previous performances, or from estimates made by men skilled in the work. Time study is the most accurate method. In most shops, records are available of the time required for jobs which have been previously done. It is a simple matter to calculate the actual machine time from which set-up, adjustment, and manipulation times can be ascertained by a comparison of machine and total times. A skilled workman or the processing engineer often can estimate time required to set up a machine, place a fixture, or adjust a tool to within a few per cent of the actual time determined by time study. Where machine time is long compared with manipulating and preparation time, an error of even 10% in the estimated time for this preparatory work will be a negligible percentage of the total time for the job.

When the time required for the various items entering into the performance of a job have been listed, they are totaled and the proper allowance for fatigue and delays is added, thus giving the time per piece. This time, multiplied by the number of pieces in the lot, plus the necessary allowance for fatigue and delay, plus the preparation time, is the **gross time for the lot.** This figure should be entered on the master route sheet as the "Time Per Lot." Hours per piece are determined by dividing the time per lot by the number of pieces in the lot. The time per lot determines how many days ahead of going into worked-material storage the particular operation must be started to get the items into storage when due there.

The instruction card is the basis upon which rates are set for performance of work in the factory. Since schedules are made up from master route sheets, and time elements are entered from data compiled by instruction cards, it is essential that these cards accurately reflect times in which the workmen can perform the jobs assigned to them. Where work is new or intricate, many shops furnish individual workmen with instruction cards for each job. Otherwise it is left to the foreman to see that his workers either know or are shown how to do the work.

ROUTE SHEETS.—Progress of work through a factory can be planned and followed in several ways. One is by use of operation sheets of which the Equipment and Tooling Schedule in Fig. 1 is an example.

FORD, BACON & DAVIS, INC.
JOB NO.
CLIENT

EQUIPMENT & TOOLING SCHEDULE

SHEET____ OF____

PREPARED BY____ ISSUE____ NO.____ DATE____ ROUGH STOCK____ PART NO.____

CHECKED BY____ SUPERSEDES NO.____ DATE____ SPEC____ MAKES____ PCS._ NAME____

APPROVED BY____ ORIGINAL ISSUE DATE____ WEIGHT PER PIECE____ PIECES PER JOB____

OP NO	OPERATION	MACHINE NAME	DEPT NO.	PIECE TIME	PIECES PER HR	SET UP	JIGS FIXTURES	NO.	TOOLS	NO	GAUGES	NO.

FIG. 1. Master Route Sheet

NAME	STUD	1 pc. 3 15/16" lg.	PART NO. 15852-W
MATERIAL	1 3/8" Rd. C-4		DRAWING NO.
Orders of 6 or more	MFG TIME 144 hrs.	MFG QUANTITY 75	S.D.

OPER. NO.	OPERATION	OPER ON S D.	DEPT.	MACHINE NO	MACHINE CLASS	SET UP	TIME LIMIT PER PIECE	EST. TIME PER PIECE
6-1	Turret	1-2	5		3" J&L Bar	3½h	15m	10m
14-2	Bench	3	5				2m	1m
	Inspect	4	5					
5-1	Mill	5	14		#2-#3 Hor.	1h	10m	6m
	Inspect	6	14					
14-1	Bench	7	18				3m	2m
	Inspect	8	18					

MASTER ROUTE CARD DATE May 2, 19– . SIGNED.........................

Fig. 2. Master Route Card for Orders Run in Large Lots

Another variety is shown in Fig. 2, which is a master route sheet for orders run in large lots. In the company using Fig. 2, a similar master route sheet was used for this same part when run in lots of 5. In the latter case, the turret lathe operation was replaced by operations on single machines, which constituted the alternate routing for small runs. The manufacturing time, or cycle for the lot of 5 was 156 hours as contrasted with 144 hours for the 75-lot run with the first operation on the turret lathe. Information on the operation sheets or master route sheets is transferred to job route sheets which have spaces for other necessary information. One of these additional items is the scheduling factor. Thus, the beginning and ending time of the job may be inserted after the schedule charts or records are consulted to see when the job can be put into production. Another factor is the allowance for spoilage and for extras to be used for repair parts or to go into stock. This factor is obtained by adding to unity, the percentage allowance for spoilage and the percentage allowance for diversion of parts for uses other than manufacture of finished product. The quantity factor then becomes a figure whose value is greater than unity, that is, it more than fills the need for the current order for completed products. This factor is multiplied by the number of pieces in a standard manufacturing lot, thus giving the number of pieces that should be started in process for each lot. The resulting figure is entered on the stores issue order. Columns may be provided on the job route form for recording the progress of the several lots through the factory under the method of dispatching used in the plant. Another method of recording progress is by means of a control board.

Scheduling

FUNCTIONS.—Scheduling is the determination of the relative time at which each operation or event in connection with manufacturing is to occur. It sets the aim, while dispatching is expected to achieve the performance.

A schedule may be formulated without any reference to calendar dates, although in its application to manufacturing, calendar dates are set for each event or operation. The interval between calendar dates set for any group of operations corresponds to the interval on the original schedule.

COMPONENTS OF A SCHEDULE.—For product that consists of individual parts grouped into subassemblies, the subassemblies then being assembled into the final product, a schedule covering the complete cycle from receipt of customer's order to delivery of finished product will be divided into several steps or periods as shown in Fig. 3 and 4. The times used in these figures are assumed and may be modified by specific conditions in individual orders, as explained in the following paragraphs.

Preliminaries to Manufacturing.—Credit checking is perfunctory for established customers or well-known companies and takes little time. Since the "customer" for many orders where finished products are stocked is the sales or merchandising department of the producing company itself, the authorization to manufacture will have been determined

before the stock replenishment order is placed. Sales department preparation of an order consists in expressing and rewriting it in the form of an actual production order, with proper identifying number and packing and shipping data, authorizing the manufacturing department to proceed with operations. The engineering department will receive its copy of the production order concurrently with the manufacturing department, and will proceed with the designing, drafting, preparation of specifications, bill of materials (if made in the engineering department), drawing lists, and all other matters concerned with the fundamentals of the structure, composition, dimensions or other limiting designations, and perhaps testing procedures of the product.

Production Planning Time.—The production planning unit of the production control department often may begin some of its work, particularly a study to fit the work into the current plant manufacturing schedule and determine a probable shipping date. From this point on, there will usually be considerable overlapping in the work of getting the order through, the objective of all departments being to get the shortest practical over-all time cycle and the earliest delivery date, with reasonable allowances for unavoidable, unexpected delays which may hold up operations at certain points. Since it is practically impossible to determine in advance, without error, the actual course of events, and since the task of finding out the exact time data and fitting them into the current schedule would be highly intricate and practically futile, good judgment enters into the relative time-fixing and the allowances for delays. Too great liberality results in idle machine and worker time and inefficient utilization of capacity unless fill-in orders for stock parts or other work can be carried along to absorb the gaps, which is not always possible. Too tight scheduling brings about delays and interruptions because of the failure of operations to fall exactly within the time program. Such delays can be made up by overtime or double shifts, but the cost of the work will then go up. At least one plant claimed a record of some 700 or more working days during which production was exactly on schedule, neither more nor less finished product coming from the assembly lines than had been scheduled each day.

In estimating the production planning time, it will be necessary to calculate how long the order will be in the planning department, as a factor in determining the amount of planning and control work, and whether this work can be done promptly to get the order into actual production at the earliest possible date. If certain drawings and data from the engineering department can be sent to the production control department in advance of completing the engineering work, and the production control department can handle them early, considerable over-all time may be saved by this telescoping or overlapping of activities. The overlapping may continue through procurement, raw materials storage and even a part of factory processing and component parts storage. The number of days to enter for production planning, therefore, is that net time during which any part of the planning process is being carried on when, at the same time, no other work which will actually advance the over-all completion of the order is going on.

Procurement Cycle.—To the extent that procurement produces a gap in the over-all cycle, its time should be recorded and added. Since

Division of Procedure	Working Days in Division: For Individual Units within Divisions	Gross (If there were no overlapping among divisions)	Net for Division (Subtracting overlap of previous divisions)†	Saved by Overlapping of Divisions	Delay Allowances Added* (net)	Total Cumulative Time up to Start of Next Operation	Starting Days Ahead of Delivery
1. Credit checking	1	1	1	0		1	154
2. Sales dept. preparation of production order	1	1	1	0		2	153
3. Engineering	48	48	48	0		0	152
4. Production planning (Use over-all time)	60	60	12	48		42	152 (start) 116 (finish)
5. Procurement (including receiving and inspection)							
a. Raw materials	30						
b. Purchased parts (Use over-all time)	36	38	18	20		50	112
6. Raw materials storage (net)‡	(12)	(12)	—	—		72	82
7. Tooling	32	32	2	30		48	104
8. Processing in factory							
Dept. 1	20						
" 2	26						
" 3	35						
" 4	32						
" 5	24						
" 6 (Use over-all time)	21	56	22	34		58	106
9. Component parts storage‡							
a. Purchased parts	(40)						
b. Manufactured parts (Use over-all time)	(46)	(50)	—	—		86	92
10. Subassembly							
Group A	18						
" B	20						
" C	22						
" D (Use over-all time)	12	46	28	18		86	68
11. Final assembly of finished product	28	28	10	18		114	40
12. Tests or final working inspections	18	18	8	10		132	22
13. Packing and shipping	10	10	4	6		144	10
14. Over-all time	—	338	154	184		154	154

* Allowances would take into account possible machine breakdowns, materials shortages, processing interruptions, unduly long time lapses in transporting materials and parts between departments, etc. Values have been omitted here for simplicity

† Represented in Fig. 4 by shaded portions of bars.

‡ Storage is considered here as merely incidental to take care of materials and parts until they are needed in manufacturing, and does not delay or add to the time of the actual manufacturing cycle.

FIG. 3. Departmental and Cumulative Time Covering the Cycle of a Production Order (see Fig. 4)

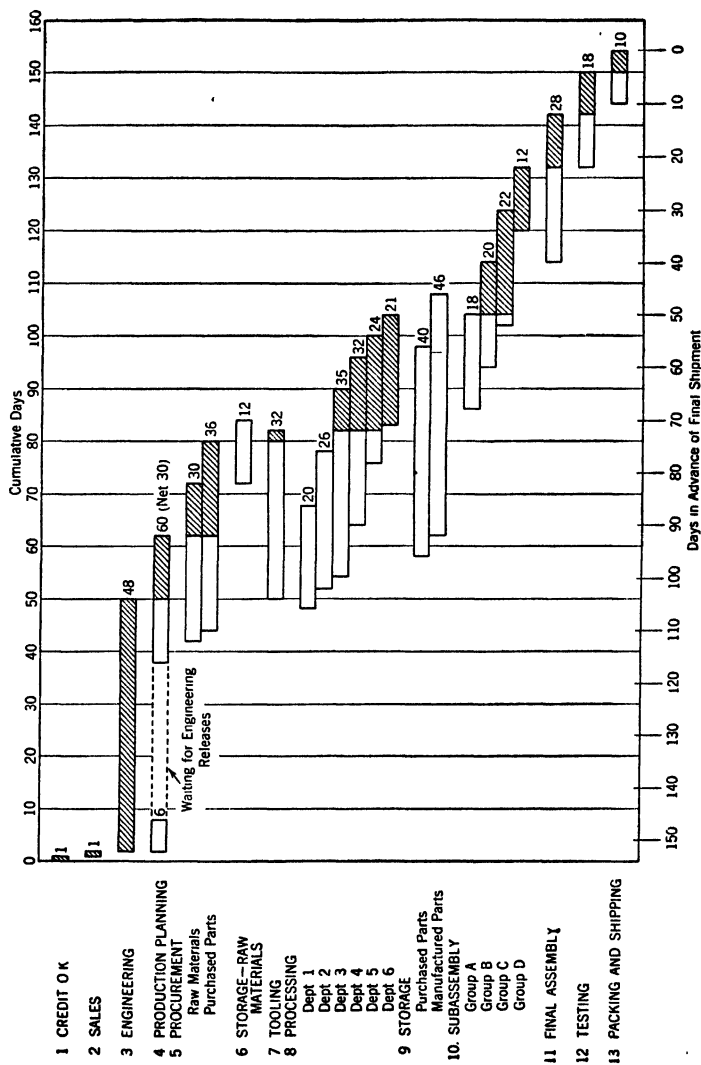



FIG. 4. Time Cycle of the Production Order of Fig. 3 in Gantt Chart Form (Shaded areas represent the net cumulative time in divisions, white areas the time saved by divisions through overlapping of work)

ordering of any materials and any parts not carried and available in stock may be carried on simultaneously and deliveries and inspections likewise may be concurrent it is only the longer of these cycles that needs to be taken into account. Raw materials storage after procurement also is a factor whose net delay effect, only, requires inclusion. If raw materials already in storage can be withdrawn to start manufacturing on parts having the longest production cycle, the fact that other materials arriving later and having short cycles may go temporarily into storage would affect the over-all time of the whole order only if such storage held up processing or subassembling.

Tooling.—Tooling is often a cause of delay unless planned early by the methods engineer, with designs and toolmaking (by outside supplier or in the plant itself) following promptly upon the determination of manufacturing methods and what new tools, jigs, fixtures, or other such devices are needed for the order. Methods and tooling studies can parallel procurement and raw materials storage and sometimes that part of planning concerned with a study of the materials situation, but may be delayed by some of the engineering work if, although drawings are sent along as completed, the parts needing tooling are among the last designed. A total and a net time can be estimated and the latter would be the time that the whole production cycle would be held up or lengthened awaiting the arrival of tools or fixtures.

In many cases the necessary tools may be available but their condition should be ascertained and any required adjustments and repairs should be made at the time the order is being prepared for production.

Factory Processing Cycle.—Factory processing of materials would be planned on charts or schedules so as to be completed in the shortest over-all time commensurate with other orders going through and the most economical utilization of equipment capacity. If it is known that the processing of parts, subassemblies, or assemblies for other orders will delay the new order at any point where the effect will be to hold up the whole order, this time should be added as part of the time for factory processing. Since the operation orders for parts and processes will be scheduled according to (1) available and open machine capacity, (2) times when materials can be obtained, (3) sequence in which parts will be needed, and (4) coordination of the subassembly and final assembly program, there will be considerable overlapping or telescoping of jobs so that a large number of parts usually will be in process at the same time. The chart or schedule covering the master scheduling of the entire order in the shops will give the net over-all processing time from start of the first part to completion of the last part. If this processing time overlaps component parts storage or subassembly, the net time of the latter—or whichever is affected—can be reduced by that much, or the net time of factory processing can be reduced by the overlap. It is probably better in most cases to schedule the processing in full and components storage or subassembly in net time (overlapping processes deducted). The Gantt chart may be used to advantage for this purpose.

Component parts storage may exist only to the extent that parts are most conveniently finished or delivered ahead of actual need and therefore must await withdrawal until required for subassembly or assembly. In such cases the time factor for this period drops out. It is only when

subassembly must be postponed because of other orders which will not be cleared through this department—whereas it has been convenient to get all parts for the order in question cleared through in advance because of availability of machines (a typical case is manufacture of finished products for stock, where there is considerable stock ahead)—that component parts storage is a significant factor in over-all production time.

Transit Time.—The time consumed in moving work from station to station in a department, or between departments, is an important part of the schedule. It is futile to set close times on machining operations to get work done rapidly, only to have to lie idle or be in transit an unduly long time and thus negative the production effort. Sometimes, however, a "safety factor" is provided by allowing, say, a day between operations for transit. If then operations are late, the parts may be handled on an express or messenger service to make up for lost time. Other fixed time allowances must be made for processing operations, such as heat-treating, japanning, etc.

Subassembly.—Subassembly time frequently overlaps with both factory processing (and component parts storage) time and final assembly time. The time of the longest subassembly group or longest subassembly series is usually the determining factor, less any overlaps, back or forward, provided this group can be gotten under way early in the subassembly cycle. If, however, the long subassembly operations must await several preliminary subassemblies, which, in turn, follow on deliveries from some of the longest parts manufacturing cycles, then there usually will be little overlapping.

On an order for a number of identical or very similar items, final assembly may overlap subassembly to a considerable degree. One typical example is in the assembly plants of the automotive industry. In other cases, as in the building of special individual machine tools, the relative degree of overlapping is reduced. It is probably better to take the overlapping from subassembly time and obtain a net for that, because final assembly is the crux of the entire program. If that can begin and end on time, the whole order will be finished on schedule, which is the major objective of the planning.

Final Assembly, Testing, and Shipping.—Testing or final working inspection time, only if one unit of product is tested, must be added in total. Otherwise the over-all time of testing the lot, or the specified number of samples, will constitute the period. The units often may undergo tests in groups, or the successive steps of the tests may be applied simultaneously as the units pass through the cycle. The net time from start to finish is then the time to include.

If a single unit is packed and shipped, the time for this purpose is the over-all time taken. Disassembly time and the time taken by special provisions for protecting against damage, rust, the elements, etc., must be included. Where a number of items are to be sent out, the sequential packing and shipping operations often may overlap final assembly so that a net time is determinable.

FORMULATION OF THE SCHEDULE.—Fixing time when an event shall occur as outlined above constitutes the formulation of a

schedule. This schedule may be applied to fixed calendar days by assuming as a zero point the date on which the delivery of the first unit of finished product is desired. The number of working days ahead of completion for each event may then be checked off on a calendar, Sundays and holidays being omitted, and the date corresponding to the number of days ahead may be fixed as the date upon which the desired operation or event is to start.

A convenient way of **ascertaining a calendar date** corresponding to any interval upon a schedule is by means of two rulers or tapes graduated at equal intervals, each interval representing one working day. One of these rulers is numbered from right to left, from zero to any number desired, preferably to a number somewhat higher than the sum of the longest purchase time and corresponding longest operation plus any allowance for storage or movement of material. A second ruler reads from left to right in calendar dates from January to December, Sundays and holidays being omitted. By setting zero of the schedule ruler opposite the calendar date at which any operation, assembly, or event is to be completed, the date upon which work should be started can be read directly under the number of days corresponding to the time allowed for that operation, assembly or event. (See Fig. 5.)

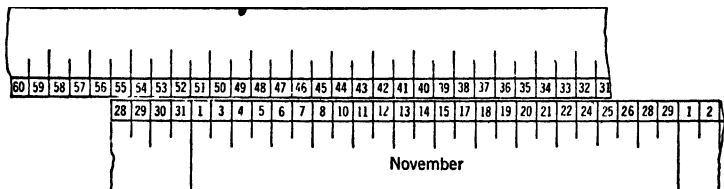



Fig. 5. Work-Day and Calendar Date Rulers

When a definite production schedule has been authorized with deliveries to commence upon a particular date, the dates upon which the various individual operations are to begin may be determined as above and the necessary purchase requisitions, work orders, etc., dated to correspond. A **tickler memorandum,** coming out on the proper date, may be used to call attention to the order, requisition, etc., which requires action at that time.

Where manufacturing is progressive or forms a **continuous process,** scheduling is considerably more simple. By progressive manufacturing is meant manufacturing in such quantity that portions of the equipment will work continually upon one part or one operation. The finished product of one piece of equipment becomes the raw material for the next piece of equipment, and work follows a route from one machine to the next without detail orders. The total volume of material that is to be manufactured, divided by the quantity of material that can pass through the equipment in a working day, determines the number of working days that will be required for the production of any particular manufacturing lot. If to this figure be added the number of days required for purchase and delivery of raw material, data are available upon which to base a schedule according to schedule dates.

MACHINE LOAD RECORDS.—To schedule work through a factory, an exact knowledge of available machine capacity is necessary. Each job routed to a machine decreases the capacity of this machine for additional work during a given period. It is essential to know whether there is sufficient time left available to take care of additional work. This information is supplied by a machine load record (sometimes incorrectly referred to as a machine burden record). In effect it is a list of all the factory equipment, and against each machine, or group of like machines, are recorded the jobs scheduled to go on the machine or group, together with the over-all time (including set-up time) required for each operation to be performed. When the total time of all such operations assigned to a machine or group of machines for a given period exceeds the number of normal machine-hours in that period, the machine or group is overloaded.

Overloading can be corrected in three ways:

1. By a change of operations which will route work to different equipment.
2. By operating equipment for longer period each calendar day.
3. By purchase of additional equipment.

The particular method adopted to relieve overloading will depend upon existing conditions. An overload that appears to be permanent in character should properly be met by additional equipment or rerouting. Overloads of short duration can easily be handled by rerouting or overtime operation. Bunching of orders, subcontracting certain work, and purchase of standard parts are other means that can be employed.

The form of **machine load record** that should be used is a matter of choice, based upon the class of manufacturing involved. If the work is largely repetitive, a sheet may be assigned to each machine in the factory. As the master route sheet for a job is made out, the total time, including set-up, required for each operation then may be posted on the machine load record against the machine which will be used. It is often necessary to record job number, part name or number, quantity, and sometimes drawing number for proper identification. If the total of all the time so entered exceeds the total working hours of the period covered, the machine is overloaded, and steps must be taken to afford relief if the scheduled production is to be maintained. If the total time assigned to the machine is less than the working hours in the period, the difference represents the amount of time that can be assigned to work other than that on schedule. If the time allocated is for specific days, then the postings must be made according to days instead of over a period.

Where **product is nonrepetitive,** other forms of machine load record may be more convenient. One such form is set up by days, as has been indicated above to be necessary where specific times are concerned. It comprises a list of machines, or groups of machines, arranged opposite a series of columns which represent working days. As a schedule is made up for any job, the number of machine-hours required for each operation is entered in the column for the day on which the work is to be performed, and opposite the group or machine to be utilized. When the total of machine-hours assigned to a machine on a given day equals the total machine-hours available, any additional work must be as-

signed to some other machine, or group, or scheduled to be performed at a later date.

A graphical presentation is usually better than a tabulation to determine machine loads on departments, except in very simple cases. The Gantt chart applied to machine loading is probably the most suitable mechanism, either on the standard Gantt progress-of-work form or by the more flexible Kardex card method. Machine load records may also be built up from punched cards in one of the punched card and tabulating systems, by use of a printing machine which automatically takes the record from the sorted and arranged punched cards.

The particular form of machine load used in any plant should be so devised as best to fit conditions. It is necessary only that it should reflect accurately the amount of work ahead of equipment and the number of machine-hours available for additional work, usually together with the specific days, and sometimes hours, scheduled, and the days or hours still available. It is frequently necessary to change machine loadings, hence job numbers, part names or numbers, quantities, and specific dates or hours should be recorded in order to facilitate alterations in the schedule.

Dispatching

FACTORS AND FORMS IN DISPATCHING.—The following factors make up the function or activity of dispatching:

1. Assignment of work to machines, groups of machines, or workmen, in accordance with the schedule shown by the route sheets, control boards, charts, or other schedule mechanisms.
2. Assignment of work as in (1) according to importance or precedence.
3. Obtaining from the storeroom any materials needed for the work, in advance of the time when they are to go into processing, or seeing that work coming from a previous process arrives on scheduled time.
4. Procurement for workmen of tools, jigs, fixtures, gages, etc., for work assigned, in advance of their being needed.
5. Initiation of inspection for each job assigned.
6. Movement of work after completion of one operation to the next operation in accordance with the sequence laid down by the route sheet.
7. Recording the time of starting and completion of each operation.
8. Keeping records of the completion of jobs.
9. Making records of spoilage or defective work, and initiating steps to replace it.
10. Recording idle time of workmen or equipment together with reasons therefor.
11. Reporting on "late" jobs, giving reasons for failure to maintain schedules.
12. Sending completed work to the next department.
13. Summarizing the active and inactive loads.

The system, forms, and apparatus used in dispatching comprise work orders or job tickets, move orders, instruction cards, idle man records, idle machine records, route sheets, work order file, dispatch racks, and time stamps or clocks. Other forms which may prove of use in a dispatch department but are not a necessity are: absence reports, tardy reports, behind-schedule tags, and lot-urgent tags.

Work Order.—The work order should convey to the workman all necessary information concerning his job or operation, such as material upon which he is to work, order number to which the work is to be charged, name or class of operation, quantity of output to produce, and time allowed for completion of job. For the information of the dispatch department, the work order should also carry the date upon which the should be started, class of machine or kind of workplace at which the work is to be done, and spaces in which the time of issue and time of completion of the job may be noted, together with the name or number of the man to whom the work may be assigned. It also should provide spaces for noting whether or not the job is finished or unfinished when the work order is turned in and, in addition, the amount of product satisfactorily completed. Such other information as is deemed necessary to fit the work order to a particular factory or industry may be added as desired. The above information, however, is essential for any type of industry that desires to control precisely the movement of its work.

An important feature of a work order form is an indication of the machine for the next operation following the one for which the order is issued. This information enables the dispatch clerk to post the succeeding operation and to expedite the movement of material to that operation at the conclusion of the job.

Work orders should be **made up in advance from route sheets** and all necessary items of information filled in at that time, excepting the names and numbers of the workmen and the particular machines upon which the work is to be performed. If there is but one machine available for the job, this information may be filled in also, but, as it is advisable to route work to groups of machines, this space usually should be left blank until the work is actually assigned. Where machines are standardized and work is routed to a group, the group to which the work is routed may be designated when the order is originally made out.

From the route sheet also is ascertained the date on which the job is due on the machine, and this information is entered in its proper space on the work order.

Work orders should be **filed according to machine class** and in sequence of the dates on which the jobs they represent are due on the machines. When a job becomes due, it is withdrawn from the file and posted to the first machine that will become idle, as explained below. Reference may be made to the route sheet to ascertain whether or not the material for the job has passed through the preceding operation and been moved to the machine. When the workman on the machine in question finishes his job, the work order posted as his next job is time-stamped and issued to him.

At the same time that the work order is posted as the next job for the machine, the tool issue slip relating to the job should be forwarded to the tool crib as an instruction to collect the tools required for the operation and have them ready for the job upon demand. It is customary in larger plants to deliver the tools to the job, but in many plants the workman still goes after tools for his job when it is ready to set up. In this case the workman, upon receiving his work order, presents the tool slips to the tool crib and receives the items called for. Information as to tools required is obtained from a tool list, carrying the same symbols and operation numbers as the work order. This list

is prepared at the time the operation schedule is made up. Tool lists are filed in the tool crib.

Upon completion of the job, the work order is again time-stamped and the number of pieces finished is entered. The workman also checks off whether or not the lot is finished. Other spaces on the card are for the purpose of figuring the earnings of the man on the job. When the work order is returned to the dispatcher, the operation indicated by it is checked off on the route sheet.

Inspection and Move Ticket.—It is inadvisable to have the workmen move material to and from their machines. This work should be done by a man delegated for the purpose. Information regarding movement of work is given to the moveman by means of a move order which carries information advising him of the location of the material to be moved, its destination, and such other information as will enable him to identify the particular material in question. A combined inspection and move ticket is made out at the time the work order and tool issue slip are written, the three forms being clipped together and forwarded to the dispatch division. On the inspection and move ticket a space, "Machine for This Operation," shows where the material to be moved will be found. Another space, "Machine for Next Operation," shows its destination. A symbol and lot number, corresponding to the symbol and lot number upon the identification tag attached to the work, identify the material. The inspection ticket is posted on the dispatch board when the work order is issued to indicate the job that is in process. When the work order is returned, the inspection and move ticket is time-stamped and handed to the moveman who thereupon moves the material and returns the ticket to the dispatch cage where it is again time-stamped.

Idle Machine Record.—Production may be stopped by reason of machine failure, tool failure, lack of manpower, or lack of material. If any of these causes occur to interfere with production, notice should be forwarded to the party who is responsible for, or in a position to correct, the error. A form of notice for this purpose is supplied to the dispatcher, who checks in the proper space the causes of delayed production and notes the time of stoppage. In the event of machine or tool failure, the original copy of the idle machine record is forwarded to the head of the maintenance department, who is responsible for machine and tool repair. If failure is due to lack of material, the record is forwarded to the materials control department so that it may take necessary corrective steps. If production is stopped due to absence of a man, the foreman of the department is notified, so that he may assign another operator, if such a course is desirable. A duplicate of the idle machine record remains in the dispatch department until the cause of idleness has been removed. The person receiving the idle machine record may then, by use of a form, initiate the advance steps necessary to rectify the cause of the stoppage. This form is made out in duplicate, the duplicate copy being retained as a memorandum to show that the work has been ordered.

Urgent and Behind-Schedule Notices.—When work falls behind schedule, it should be so marked as to attract attention at all times until the necessary steps are taken to bring it back into its proper schedule position. This result is usually accomplished by attaching to

the work order or orders that are behind, a card of distinct color which serves as a notice to give precedence to the lot over other lots or orders assigned to the same group of machines. The card may be of any distinctive color except red. When attached to a work order, it gives that work precedence over other work of presumably equal standing. Should a number of jobs fall behind schedule so that it becomes necessary to expedite one of these ahead of the others, a special form may be used. This form is usually printed in red, or upon a red background. A work order with this red card attached should receive precedence over every other work order in the file and pressure should be kept upon it until it has been brought up to schedule.

WORK ORDER FILES: ROUTE FILES.—Work orders, after having been prepared, should be filed ready for use in such manner that they are easily accessible and will become apparent at the date when the job indicated by them should be put into process. Methods of doing this are: (1) filing in trays and boxes according to class of machines or workplaces, cards in each tray being filed in order of dates upon which work should be started; (2) filing in trays and boxes, according to order or lot numbers, the cards for each order or lot number being filed in order of dates on which work is to be started; (3) filing in pockets of route files.

Filing **according to classes of machines** is generally used when work is routed to a group of machines, and in that case a particular lot is dispatched to the first machine of the group which becomes idle, after the work order has appeared in its regular sequence in the file.

Filing **according to order or lot numbers** is used where work follows a definite sequence through a particular set of machines. In some classes of manufacturing, certain kinds of work can be done on certain machines and on no others. These machines are usually located in one department, or group, and the work is routed to the department. The dispatcher is responsible for keeping the work moving by posting the next succeeding operation at the same time he issues a work order for any particular job. Route sheet in this case shows only the department to which the work is routed, and the work is checked in and out of the department instead of in and out of several operations in that department.

Filing in **route files** consists in collecting all route sheets relating to the component parts of a given assembly, and assembling them together with a series of sheets fitted with pockets to contain work orders, move orders, and inspection orders. A set of pockets facing each route sheet is bound in the file and the various orders called for by the route sheet are filed in these pockets—work orders, move orders, and inspection orders being filed separately and arranged in the order in which they should be issued. The theory underlying this method of filing is that each job would be checked as started on the route sheet as soon as it is issued, since it will be necessary to go to the route file to obtain work order. Under this system a route file is made up for each lot or order sent through the factory.

The route file was originally devised by Frederick W. Taylor and was installed in plants organized by him and his associates. It is somewhat cumbersome and difficult to handle, and may cause congestion at dis-

patch stations, since finding the work, inspection, or move order in the file and checking off operations consume appreciable time. This condition may assume serious proportions, especially if a number of men complete their job at the same time, and may cause a considerable amount of production time to be lost. This disadvantage more than counterbalances the advantage of immediate checking of progress of work. In fact, with a proper organization and training of dispatchers under methods (1) and (2) above, checking of progress of work need not lag over 15 to 20 min. behind the actual work of the shop.

DISPATCH RACKS.—Dispatch racks are used for posting work orders to indicate the work in process at any machine or workplace and the jobs ahead of each machine or workplace. In some cases dispatch

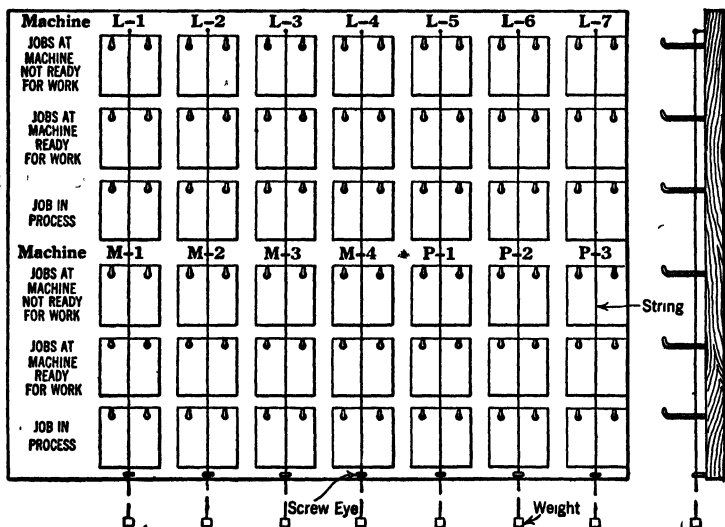



Fig. 6. Typical Hook-Type Dispatch Rack or Bulletin Board

racks post work for individual workmen instead of to machines. In general, the method of posting will be determined on the basis of conditions surrounding the work and each case must be decided upon its merits. The form of the dispatch rack is unimportant. Whatever form is adopted, the rack must show all places where work can be performed, and also the job in process, and at least one job ahead of each machine or workplace. Either hooks or pockets may be used on the rack for posting work, although hooks require that orders be punched. Fig. 6 shows a typical hook-type dispatch rack or bulletin board. Each machine or workplace has three sets of hooks, one for the job in process, one for the next job ahead, and one for jobs assigned not yet ready for

work. The work in process hook carries a duplicate of the work order, the original being given to the workman. Other hooks either carry the duplicate work orders, the originals being in the route files, or both duplicates and originals, depending upon the system used for filing work orders.

TIME STAMPS.—It is advisable, although not absolutely necessary for the purpose of dispatching, to record the times at which jobs are started and completed. If the time is not recorded, cost accounting will not be possible, records on wage incentives based on standard time cannot be kept, and it will not be possible to fix responsibility for delayed jobs. It is advisable, therefore, to make time recording a function of the dispatcher's job. For this purpose recording time stamps or time clocks are generally used. Any of the more generally used types of time stamps are satisfactory, but preference is given to those which record the time in figures which are direct reading.

Time stamps or clocks controlled by a master clock are recommended for dispatching work, where there are a number of dispatch cages in different departments of the factory.

DISPATCHING WORK.—Where work orders are **filed according to classes of machines or workplaces,** and also according to dates upon which work is to be started, the various orders for each class of machine are removed from the file the day previous to the day upon which work should be started. Originals and duplicates are filed in "jobs ahead" pockets of dispatch racks. The stores department, upon receipt of the stores issue slips in advance, should have delivered the material necessary for each job to the designated group of machines, and notified the dispatcher of this delivery, or the dispatcher may be responsible for sending a move man with a stores issue slip to get the material in advance of the time when it will be needed. The fact that material has been delivered should be verified by the dispatcher before posting work orders to machines. After the material has been delivered as required, when a workman in the group of machines to which a particular order is assigned finishes the job upon which he is working, the first order in the jobs-ahead pocket is time-stamped and handed to him. The duplicate is posted on the board in the pocket of the particular machine or workplace where the work is actually being done. When the job is completed, the workman returns his original copy of the work order to the dispatcher, who again time-stamps both it and the duplicate and issues the next job to the workman as before. Information as to the quantity of acceptable work completed and the amount rejected by the inspector is transferred to the duplicate work order. The original work order is then turned over to the clerk in charge of the route sheets and the duplicate is forwarded to cost department.

The procedure when work orders are **filed according to order or lot numbers** is much the same as when filing according to classes of machines. In dispatching work that is routed to a group of different machines which are operated on a definite sequence to produce a particular item of product, it is not always necessary to check individual operations on the route sheet. In such cases these successive operations may be grouped as one, and the dispatcher held responsible for securing prompt performance of each operation, in sequence, upon completion

of the preceding operation. Work orders in this case may be clipped together and, when one operation is posted as in process at a machine, the next succeeding operation is immediately posted as a job ahead of the next machine in the series. To have the work move smoothly and rapidly through the group of machines, it is necessary then for the dispatcher to see only that material is moved promptly from one machine to the next upon completion of the prior operation. The route sheet is checked to note the arrival of the work at the group or department, and is again checked to show when this work is completed. If it is necessary to ascertain what progress has been made between the time that the work enters the department and leaves it, all that is required is to examine the incompleted operations as shown by the work orders.

Dispatching work by **groups of machines or departments** in the manner described above is desirable when operations are relatively short, and where there is a definite sequence which must be followed. Checking work on the route sheet in and out of the department will eliminate a considerable amount of clerical labor, and yet give all the necessary information for tracing and recording progress. This method is hardly suitable where work may pass through a variety of operations in different sequences, on different jobs or order numbers. In such cases it is best to check the route sheet, operation by operation.

When dispatching work in connection with **route files**, the procedure is somewhat different. The original work order issued to the workmen is filed in the pocket in the route file as heretofore described. The duplicate is posted on the board or rack as a job at the machine not ready to be done. When the material for the job arrives at the machine or workplace, the duplicate is moved ahead and posted as a job at the machine ready for performance, being arranged in the rack in its proper sequence relative to other jobs at the machine. When the workman finishes the job upon which he is working, the first duplicate work order posted as a job at the machine ready for work is moved to the job at the machine pocket and the original corresponding to it is removed from the route file, time-stamped, and given to the workman. At the time when the work order is removed a half check is made in the check column of the route file, and this check is completed when the original job ticket is returned, showing that the work is done.

In connection with these route files, a **timetable or schedule** should be built up by showing the dates at which the various jobs arrived at different machines. Since the work orders are buried in the route files, it is impossible to file them by dates and thus insure their being posted at machines upon the dates due, as is possible with two systems heretofore described where work orders are filed in trays in order of dates. Furthermore, the route file system usually requires handling the two route files for each change of card, the first route file pertaining to the order or lot number upon which the workman has been working, the second route file covering the job upon which he is to work. The workman, therefore, is held at the dispatch window for a longer period than when the dispatching operation consists simply in removing two cards from a dispatch rack pocket, handing the original to the workman and depositing the duplicate in the rack.

Arrangement of Dispatch Cages.—Dispatching may be done either from a central dispatching office or from departmental dispatch cages

located at convenient points throughout the factory. Where the factory is relatively small, so that men will not lose an excessive amount of time going to and from the dispatch cage, a central dispatch department is advisable. It is then possible to collect in one spot all information necessary for moving work through the factory. Dispatch clerks and clerks in charge of route sheets are in one place, and checking can be done immediately after work orders have been turned in by the workmen. With such an arrangement, the time elapsing between the completion of a job and its checking on the route sheet may be kept within close limits.

MOVEMENT OF WORK.—An important function of the dispatching department is to secure prompt movement of work after completion of an operation, from machine or workplace to the location where the next operation is to be performed. The most efficient method of handling such transportation is by means of move men who receive their instructions from move tickets, combined inspection and move tickets, or, in very simple systems, perhaps merely by verbal orders, with identification or route tags marking the work to be moved.

Mechanisms for Production Control

FIVE CLASSES OF MECHANISMS.—There are five different major classes of mechanisms used for the purpose of production planning and control. By means of the proper selection and application of suitable kinds of these mechanisms, production control systems are operated and records are kept. The five classes are:

1. Production control boards and mechanical systems.
2. Visible index or card record systems.
3. Gantt-type charts.
4. Punched card and tabulating equipment.
5. Duplicating or printing equipment.

CONTROL BOARDS AND MECHANICAL SYSTEMS.—In the control board and mechanical class there are several important kinds of equipment:

1. Small three-pocket wood racks (machine loading).
2. Hook boards.
3. Pocket-strip or grooved-label strip boards.
4. Spring-clip panel boards.
5. Tape or string boards.
6. Index-Visible boards.
7. Racks with movable data units.
8. Pictorial boards.

POCKET RACKS: HOOK BOARDS.—Two of the above date back originally to the time of Taylor but are still widely employed in various applications and for many purposes are the best and most convenient devices. One of these is the three-pocket wood rack in which work tickets are filed, already mentioned in this Section. The other is the hook rack, which is shown in Fig. 6 and is further illustrated and explained in Figs. 7 and 9. Both types are highly useful in visual systems for the dispatching of work in local departments, or in the central

dispatch offices of plants manufacturing a considerable variety of products.

POCKET OR GROOVED STRIP BOARDS.—Another form of board uses pocket strips or grooved metal label-holder strips across the board for the insertion of tickets or cards identifying the item posted. The hook, pocket, or grooved strip board may have parts or products listed down the left column of the boards, and a department or machine list horizontally across the top. The cards or tickets are moved to the right as work on the various parts progresses through the various departments or machines. A time scale may be used horizontally in place of the departmental or machine scale, in which case the identifying tickets should have starting and completion dates noted on them, and may carry all the operations on one ticket, or may require the use of a separate ticket for each operation, posted under its starting date. If a single ticket is used, it would have to be moved as the work progresses. This plan is not so good. Separate tickets enable scheduling to be shown on the board, as well as progress of work, and make the board much more useful.

USE OF PRODUCTION BOARD FOR CONTROL OF MANUFACTURING.—The production control schedule board (hook type) used in the Brown Instrument Co., described here by D. C. Carter, and pictured in Fig. 7, is one of the tools used for controlling manufacturing to insure that proper balances of all materials, supplies, and finished parts are maintained in the storeroom. In addition, it reflects the work record of all machines in the plant.

Planning.—In creating a manufacturing order, the product planner, who is responsible for planning and ordering all component and detail parts required to assemble those instruments under his supervision, establishes quantities needed and the date that these quantities should be completed.

The order is then published on route sheets which go to various sections of the production control division for further handling. One copy (planning, Fig. 8) is sent to the statistical group for inserting of machine numbers and travel time. One copy (material requisition) is sent to the raw materials or finished materials stock record division for deduction. One copy (dispatching) is sent to the tool checking division, and the remaining copies to the release desk. Each group receiving a copy of the order performs an individual job and forwards the copy to the release desk. When all copies of the order have been returned, the order is then released to the scheduling group.

Upon receipt of the order the scheduling group have load tickets made out for all machine travel time. These tickets are made up from information supplied by the statistical group on the planning copy, regarding the types of machines and the travel time for each operation. A color code is used for operation identification, as follows:

A green ticket indicates the first operation to be performed in the machine shop.

A yellow ticket indicates intermediate operations between the first and last operations to be performed in the machine shop.

A blue ticket indicates the last operation to be performed in the machine shop.

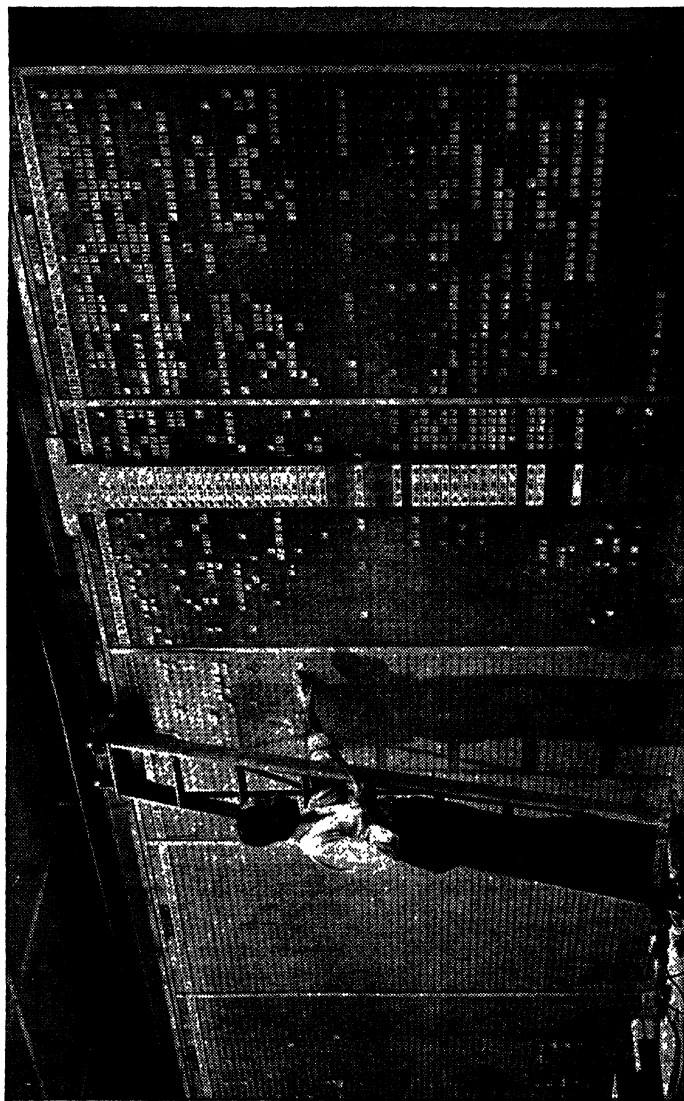



Fig. 7. Production Control Board with Hooks for Posting of Operation Tickets

Quantity 1000 | 20'/C 7.5#/C

PRODUCTION ORDER
PLANNING

F-895 8-43 10M PRINTED IN U.S.A.

1 K.

Part No. 78788 E

Order No LOT 1

Part Name Chassis Latch Stud

Material 3/8" dia. C.R. Steel B-527

Die Size OCT 25 19–

Date Written | Date Due 11-10-

Oper No	Operation Detail	Dept.	Machine	Tool No.	Sch. Date	Hrs/C	Hrs/Lot	S.U.	Mch. Ld.
1	Turn, burr, form, knurl and cut off.	1	#0 B&S A.S.M.	126	11/1	4.70	47.00	5.0	52.00
2	Drill and burr #55 hole	1	D. P.	22 78788	11/4	1.03	10.30	.5	10.80
3	Inspect	10							
4	Ferrocote	3			11/7				
5	Stock	14							

RELEASED NOV 1 19–

Date of Master 6-28- Superseded Master Dated

Date Completed

Total Pieces Run | Total Scrapped
Total Salvaged | Total O. K.

FIG. 8a. Planning Department Copy of Manufacturing Order (*face*)

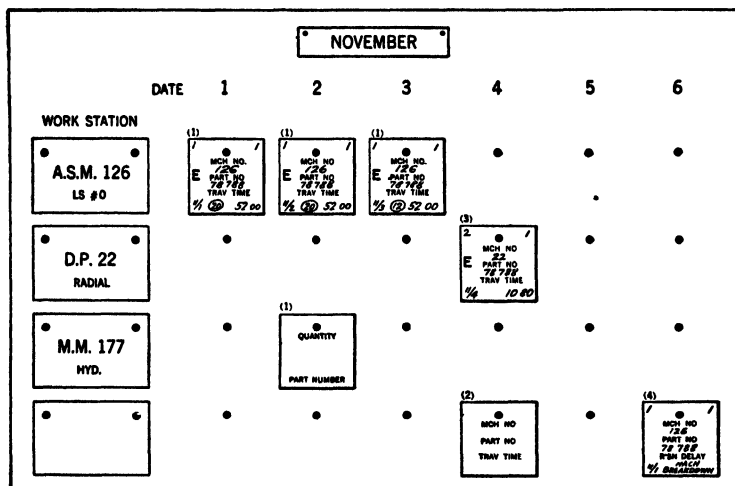
The orders are then scheduled to run in time to meet the due date set by the planner according to the travel time involved and the available machine capacity on the various types of equipment needed. These tickets are then placed on the control board (Fig. 9) under the scheduled starting date, adjacent to the machine on which the operation is to be performed. They are placed on the board with the front side of the ticket showing. All copies of scheduled orders, except the planning copy which is placed in the work in process file, are withheld at the scheduler's desk and filed according to the starting date of the first operation. One week in advance of the scheduled starting date, the orders are dispatched to the various group leaders. This procedure has been established to allow the raw materials storeroom and the tool crib to prepare and handle their obligations in order to have all materials, tooling, and equipment ready when needed.

OPER. NO.	NO. PCS. WORKED	FIN. GOOD	NOT FIN.	NO. PCS. REJ.	EMPL. NO.	INSP. NO.	DATE	REMARKS

Fig. 8b. Reverse of Fig. 8a

Control.—As notification is received from the machine-shop dispatcher that processing of any operation on a part has started, all the tickets for that operation are turned over on hooks adjacent to the machine number, starting on the current date and extending for future days, according to the number of hours required to complete the operation. Now the tickets are on the board with the reverse side of the ticket showing. This indicates that the part is running on that particular machine. Tickets representing the day's performance are removed by labor evidence notifications (time card, Fig. 10) from the machine shop each day.

With the control slide adjusted to the current date, any card to the left of it indicates that production on that particular part is **behind schedule.** If the hooks to the right of the control slide are empty, it indicates that all parts scheduled to run on those days are completed **ahead of schedule.** If the slide is on the current date and the tickets are turned over on the same day, it indicates that the parts are being run **on schedule.** It is possible to place one, or more than one ticket on any one hook, depending on the number of hours of machine travel time needed to complete each operation.

The scheduler is notified by means of telautograph when any delays hold up the work and the reason why. Pink tickets are immediately filled out and placed on the board over the first ticket of the operation delayed. Therefore, if any ticket on the schedule board has a pink ticket attached, it is an indication that trouble has developed which requires special attention. These troubles might be any of the following: tool trouble, material shortages, machine breakdown, no operator available, etc. When a pink ticket is placed on the board, the proper

(1) Green tickets. Used for first operation in machine shop. Entries are (upper left) operation number, (upper right) lot number, (letter) planning group, (center) machine number, part number, (bottom) scheduled starting date, machine load per day, total machine load in hours. Tickets are turned to reverse side when job is running, as shown in ticket on third row from top, entries being (top) quantity on order, (bottom) part number.

(2) Yellow tickets: Used for intermediate operations between first and last in machine shop. Entries same as on green tickets.

(3) Blue tickets: Used for last operation in machine shop. Entries same as on green tickets.

(4) Pink tickets: Used for jobs on which trouble is occurring. (Bottom) scheduled starting date, reasons for delay.

Fig. 9. Diagram Illustrating Use of Production Control Board in Fig. 7 (Name plate is reversible. Dots represent brass hooks for tags.)

person qualified to help eliminate or correct the condition is automatically notified.

By use of the control board it is possible quickly to compute, at any time, the hours of work ahead of any machine or battery of machines. The board also shows a visible record of those parts which are behind schedule and, if a pink ticket is attached, the reason why the part is behind schedule, and the group of instruments that will be affected by the delay. The board is also flexible enough to allow for inserting rush orders on any machine or group of machines at any time without creating too much disturbance in the shop or in the schedule set up for the shop to maintain.

The accompanying illustrations (Figs. 7, 8, and 9) will clarify the method employed in posting tickets on the board, the different symbols and positions used to identify the parts, and the paper work used both to place the tickets and to remove them.

Emp. No.	Name	Quantity on Order		Part Number	78788
116	Joel Jones	Balance at Start of Job		Order Number	L-1
Machine No. 126	126	Quantity Defective		Account Number	
*Dep't No 11/1		Set-Up Rate		Operation Number	1
Group No.		Allowance		Quantity Paid for	100
Nov. 2 21.50	Stop	Rate/o		STD COST / UNFAVORABLE / FAVORABLE	
Nov 2 16.80	Start	Earnings		Approved	
Emp Rate 4.7	Elapsed Time				
Remarks					

FIG. 10. Time Card Used with Production Control System

Results Secured.—This master control board has been found to be the best means for planning and bringing about the movements of materials, performance of machines, and operations of labor, no matter how subdivided, so that they will be controlled and coordinated as to quantity, time, place, and cost. The control board accomplishes these purposes because it:

1. Permits scheduling to be preposted for each production cycle (3 months).
2. Permits each productive machine in the plant to be weighted for its full operating capacity. This weighting takes into consideration such basic factors as production time, transportation time, set-up, clean-up, maintenance, etc.
3. Provides for an accurate and effective correction to be made in machine loading to adjust control problems which are inevitable in a complicated kind of manufacture.
4. Enables such corrections to be made immediately, since it gives an over-all picture of plant operation.
5. Takes full advantage of economical operation by limiting set-up costs and extending economical lot manufacture.
6. Takes full advantage of the relationship of any correction to the rest of manufacturing, whether it concerns a part passing over a machine or the relationship of a machine to other operations.
7. Permits standardization of tooling set-ups and parts manufactured.
8. Allows inventories to be reduced to a minimum.
9. Aids in having theoretical schedules accomplished.
10. Accurately coordinates the planning, preparation, and production cycles.
11. Makes available to all persons involved full knowledge concerning their objectives.
12. Permits more accurate planning and preparation.

A production control board will not automatically bring about such results, although there are within its structure features which go a long way in bringing about these advantages. For instance, it has strong psychological advantages in that it expresses what the manufacturing organization should do and how well it is doing it, thus overcoming the tendency to offer excuses and alibis for failures. The board does not

argue or cause emotional upsets. It just stands in its place and displays evidence of any delays, upsets, or problems and as a result these difficulties are realized, understood, and solved.

MACHINE LOADING BOARD.—One concern, producing aircraft parts, sets up a board of the pocket type listing 750 machines occupied in turning out work. The board lists the 250 different types of machine tools, the number available of each type, their position in the plant, and the total number of hours each one is in operation per day. By a glance at the board it is possible to determine the distribution of the machines in the 13 departments involved and the total loads imposed on all the types of machines. Thus, if operations of a certain kind create a demand for more machine-hours than are available, the time figures for machines working at peak loads, posted in red, signal a warning that some other machines may have to be allotted part of the task.

The board has proved its usefulness in many ways. Potential machine bottlenecks are spotted before they develop. Master mechanics are able to prepare for shortages of machine tools by converting other machines to tasks for which they were not designed. (Automotive War Production, vol. 1.)

SPRING-CLIP PANEL BOARDS.—For the control of production, as well as inventories, machine loading, tools, and many other factors in manufacturing, the McCaskey record system employing spring-clip boards for holding standardized copies of the various necessary

MANUFACTURING ORDER

DATE ISSUED	4/18	ORDER NO.	108
DATE WANTED	5/20	QUAN. ON ORDER	1000

DESCRIPTION

PRODUCTION RECORD

DEPT.	SCHEDULE START	SCHEDULE FINISH	DATE STARTED	DATE FINISHED	QUANTITY FINISHED
2	4/22	4/25			
4	4/26	4/30			
5	5/2	5/3			
6	5/4	5/12			
8	5/12	5/15			

Fig. 11. Manufacturing Order for Spring-Clip Board

SCHEDULE TICKET

DEPT. 2

ORDER NO. 108

QUAN. ON ORDER 1000

SCHEDULE

START	FINISH
4/22	4/25

DATE STARTED

DATE FINISHED

QUAN. FINISHED

REMARKS:

FOREMAN

FIG. 12. Schedule Ticket for Board

forms has long been in successful use. One typical form has 10 vertical rows of clips with 10 horizontal rows down the board. The back of the board is similarly arranged, and panels are mounted in groups on hinges so that all but the one to be looked at can be swung back out of the way. Under typical job-order production, manufacturing orders (Fig. 11) are made out in the usual way, several copies being produced by means of carbon-backed forms. A copy is kept in the central production or planning department and often other copies are sent to the various departments performing operations on the order. Start and finish dates for the work to be done in each department are determined and listed. One set of triplicate schedule tickets (Fig. 12), on white, yellow, and pink forms, is then made for each department, specifying these start and finish dates.

In the central control section, the manufacturing orders are filed on the order control board (Fig. 13) either consecutively or according to the last two digits of the number, where the latter plan adds facility to operation. On the central schedule boards for the various departments there are two vertical rows of clips for each day and date. One row is for orders to be started on that day and the other is to hold the

tickets of orders finished on the day. The white copy of each schedule ticket is posted under its date in the "start" column. There are usually 10 clips down the date column and the schedule tickets are filed under these according to the last digit of the order number; for example, order 1683 under clip No. 3. The corresponding yellow and pink copies of the schedule tickets go together to the department doing the work and are there posted together on the board, according to last digit in order number, under the scheduled starting date of the operation, and in the "start" column of that date.

Fig. 13. Production or Planning Board, Central Control Department

When production is actually started, yellow and pink copies are removed from the shop board, the actual starting date is put on them, the pink copy is filed under the "finish" column for the job, and the yellow copy is sent to central control, where it is filed under the "finish" column of the corresponding date. The white ticket is removed from the "start" column and filed with the manufacturing order, on which is entered the actual starting date. When the job is done the pink ticket in the department is removed, the actual finishing date is entered on it, and the ticket is sent to central control. Here the pink ticket is removed from the board and filed with the manufacturing order, upon which the finishing date is recorded. After all departments have finished their work, all tickets are removed from the order control board.

WORK ORDER

Contract No. 971 Date 8/19

MATERIAL REQUISITION & STOCK RECORD

No. 31429

Req. No. Date 8/ 19–

Article 27 Gauge Steel, Stretcher Levelled, 30x80

Deliver to Dept A

Chg Act Order No. 971

	NO PIECES	QUANTITY	PRICE	UNIT	AMOUNT
IN STOCK					
AM'T. DEL.	500	sheets			
BAL. STOCK					

ISSUED BY F. S.

REC'D BY R. G.

COST DEPT. CHARGE

BRO'T FWD

THIS CHARGE

TOTAL TO DATE

PRODUCTIVE TIME TICKET

MONTH		DEPT NO	ORDER NO	CLOCK NO
8/21	Y.	A	971	78

EMPLOYEE Mike Finn

PART NO A 37C

QUANTITY 10,000

OP NO 1

OFF ON OFF ON

OPERATION NAME

MCH. NO.

MCH. HRS.

	PCS. FIN.	SCRAP	NR	RATE	AMOUNT
THIS TICKET	1800	40			
PREVIOUS TOTAL	7200	500			
TOTAL TO DATE	9000	540			

BONUS CLASS

STD. TIME

OK

FOREMAN

Fig. 14. Progress of Manufacturing Order Through Successive Operations

A variation of the above procedure, suitable for longer runs where total production rather than start and finish dates is the controlling factor, is provided by setting up the left-hand vertical columns of a series of boards to hold work orders, the rows of clips extending horizontally across the board being used for successive operations on the order (Fig. 14). With the work order are filed the necessary combined material requisition and stock record forms. As production time tickets covering work done on the successive operations arrive from the shop departments, they are filed on the proper horizontal line (work order number) under the sequential operation number (1, 2, 3, etc.) clip until the entire job is completed. Production time tickets show cumulative good work and cumulative scrap, as well as time, the last ticket from an operation being placed on top under its clip until the run is finished at that operation. Meanwhile, parts lots will have been sent along to succeeding operations from which reports will likewise be coming. Corresponding move orders may be made out for the work, or combined time-move tickets, if it is desired to keep track of the location of lots.

If it is desired to check on completion of orders, boards may be set up with dates from 1 to 31 and copies of manufacturing orders due on the various dates may be filed under the proper clips. These copies are removed as soon as orders are finished.

For departmental control, boards similar to the above may be set up. The work order for a job may be filed under a spring clip and, as production comes through, duplicates of the successive time and move tickets sent to central control may be posted under the clip, cumulative data showing on the top ticket. Order completion boards with dates from 1 to 31 may be used on which to put copies of work orders under their due dates.

Machine Scheduling and Load Control.—While machine load scheduling can be carried on with separate boards of the same kind as used for production control—using three clips for each machine—a preferred method is the use of a series of special machine control sections (McCaskey). These sections are vertical and consist of seven units, each unit being assigned to a machine, and being made up of a double pocket with a spring-clip on the front, thus giving three filing positions for each machine. The vertical units may be bolted together at the side to form as many vertical rows as desired, of seven units each. Labels beneath the clips mounted on the front pockets of the units identify the machines to which the pockets have been assigned.

The boards are mounted at the local dispatching center or in the foreman's office. Each installation has sufficient units for all the machines or pieces of equipment in the manufacturing area. The work orders, job tickets, or time tickets are sorted and filed on these boards in the pocket units for the machines where the operations will be done, as jobs ahead, jobs next on the machine, jobs on the machine:

1. Back pocket—jobs for which material is not yet available, arranged in sequence of order number or of expected performance.
2. Front pocket—jobs for which material is on hand and ready so that the work can be put into operation (next jobs ahead).
3. Under the spring-clip—the jobs currently on the respective machines and in operation.

If no tickets are filed in the "next job ahead" pocket for a machine, the dispatcher or foreman knows that the particular machine will be down unless some new work is secured for it, or some forthcoming job is reassigned to it. Such changes are quickly made if work is available. Workers, likewise, may be transferred to other machines if there is no job for the machine which they have been running. Overloads on one piece of equipment often can be spread over other machines to get production out earlier than would otherwise be possible.

A machine load form may be used for each machine to indicate the date up to which the machine will be occupied with work. Such a form may consist of a simple card with dates 1 to 31 down its two long edges so that the last date of its scheduled work can be circled with a pencil or tabbed with a clip or colored signal. As new orders come through, the date will be advanced. The machine load cards are filed under the spring-clip or in the front pocket so that they may be readily available for changing schedules or assigning new work, and cutting down man and machine idleness. These cards could be based on productive hours scheduled ahead, but this plan requires two steps—subtraction of hours when each job is finished and addition of hours for new work, whereas beginning and ending dates often have been determined and recorded by the planning section when getting the order ready for production, so the use of dates is preferable.

Boards with spring-clips may also be set up for machine scheduling with the horizontal rows of clips constituting a time scale by days or hours. The left vertical row of clips would carry the work orders as an index, and productive time tickets or move tickets, or other markers, could be used to chart the time when the job should begin and end.

TAPE OR STRING BOARDS.—Another variety of board is that employing movable tapes or strings horizontally across the board for the recording of progress of work. One such board—Produc-Trol—has been used extensively in purchasing, materials or inventory control, machine loading, order scheduling, production control, assembly, personnel control, control of tools, in connection with wage incentive plans, and for practically all other control purposes (see Fig. 15). On the left-hand side of this board is a pocket panel in which are inserted record cards with a visible identification line, while the right-hand side of the board is divided into a series of peg holes for visible charting. A heading strip is available for listing across the top of the pegboard section such divi-

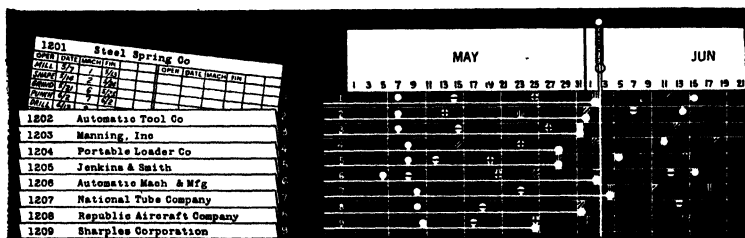



FIG. 15. Production Control Board, Movable Tape (Produc-Trol) Type

sions of time, quantity, or date as may be required; or this heading strip may be used to divide the board into departmental divisions.

Each card in the visible index panel is aligned with an "item line" on the pegboard section. Each "item line" consists of two lines of peg holes. Basically, the use of the upper of these two lines of peg holes is to indicate, by means of signal pegs, the scheduled operations to be performed. The lower of the two peg hole rows in each "item line" is used for the tape peg to record progress against schedule.

The tape peg is just what its name implies—a peg to which is attached a tape or cord. By means of an assembly not visible on the face of the board, this cord is always at tension no matter whether its peg be in the first peg hole or in the two-hundredth peg hole. Each tape peg is numbered to correspond with the "item line" it covers.

Signal pegs are available in twelve contrasting colors, each in four shapes, and any signal pegs may be provided with numbers or identifying symbols as indicated by the application of the particular installation.

By the use of colored vertical cords, automatic control elements may be introduced. The relationship between these vertical cords and the signal and tape pegs indicates at a glance whether work is behind or ahead of schedule and by how much in terms of whatever divisions have been set up by the heading strip.

In some 3,000 installations, ranging from a single board to more than 200 boards, applications have been varied to meet a wide range of conditions in individual companies, from the internal controls noted above to those covering large-scale outside operations. One installation, for instance, covers the movement of freighters through the Great Lakes, another air traffic on a transcontinental airline, others the assembly, order scheduling, purchasing, etc., in plants engaged in many different lines of manufacturing.

INDEX-VISIBLE BOARDS.—Typical of the index class is the production order control system maintained by the Treadwell Engineering Co. with listings on Index-Visible cards (Remington Rand) filed on special leaves housed in ringbooks. An illustration is shown in Fig. 16. The cards are blank, except for the printed horizontal and vertical lines, a single heading card being used at the top of each leaf to identify the information. Any card may be quickly unbuttoned from the runway or simply slid up to expose any additional notations below the visible margin.

Cards are filed by order number and remain in place until the order is completely shipped. Inasmuch as some orders require much longer to process than others, the listing is in constant state of flux. All completed orders are instantly removed, leaving only orders in process in this record. Progress of the order through various steps is indicated in the squares at the right of the visible margin. The due date and promised shipping date are also shown, permitting visual reviews to be made frequently to check any orders on which expediting action is needed.

RACKS WITH MOVABLE DATA UNITS.—An ingenious mechanism for production control, procurement of materials, control of finished stock, and control of shipping is the flexible rack-type installation. It consists of vertical racks made of double uprights of small pipe

DATE	ORDER NO.	TO SHOP	JOB	CUSTOMER	MATERIAL	DUE	PROMISES	SHPD	P	I	S	PUR	M S
4/23/—	T100600	4/24/—	WS-563	Continental Can	Bar Strips	6/30/—	A-1-A 6/28/—			6/8	5/23	5/18	4/30
4/23/—	T100605	4/25/—	WS-610	U. S. Mfg. Co.	C. R. Sheets	7/15/—	A-1-B 7/10/—					5/10	5/5
4/24/—	T100629	4/27/—	WS-702	A. B. C. Corp.	Bar Strips	7/10/—	A-1-A 7/2/—				9/18	5/16	4/29
4/27/—	T100664	4/29/—	WS-759	X. Y. Z. Co.	H. R. Sheets	7/27/—	A-2 7/25/—				6/1	5/27	5/9
4/28/—	T100715	4/30/—	WS-767	U. S. Mfg. Co.	C. R. Sheets	8/15/—	A-2 8/20/—						5/4

Fig. 16. Index-Visible Production Control Board with Removable Cards

fastened to the floor, and 1½ x 1-in. wood sticks, 36 in. long, on each of which is mounted with thumbtacks a cardboard strip for recording scheduled and accomplished work on any order. Spring clips on the backs of the sticks, one near each end, allow the sticks to be clipped to the pipe racks, at any desired point or level. There are several racks, one for each department, including engineering, production planning, materials procurement, the respective shop departments, finished stock, shipping, and sales. Order sticks are placed on the first rack when engineering work is started, and are transferred from rack to rack as the work progresses. Detailed postings covering the work are entered in the respective blocks on the cardboard strip as the order goes through.

PICTORIAL BOARDS.—Some companies have used pictorial boards for showing progress of work. One such board used in an aircraft plant showed the layout of the assembly plant and the location of the adjacent flight testing field. Preliminary operations departments were noted. On the assembly lines aircraft diagrams marked off the various assembly stations. Manufacture was controlled according to plane numbers in a lot going through. Spaces were left on the layout diagram so that each day when the production report arrived, the plane numbers could be posted to the stations where these respective planes were under subassembly or final assembly.

Visible Index or Card Systems

VARIETIES OF SYSTEMS.—One of the most widely used mechanisms for control of production is the card system. As compared with production boards, the card system occupies far less space, is highly accessible, brings pertinent information together in a condensed form, offers greater facilities for checks and comparisons, and reduces the personnel required for record keeping. It may be less costly to install and operate. The visual and graphical features of the production board and of Gantt charts are lacking, however, and the latter are often much more serviceable and practical in shop departments for local control of operations because they are directly understandable and dynamic. Written or posted records, while necessary, are static in that they require interpretation into physical factors. They are of greater service in central production control departments where capable clerical personnel is available.

Card systems may be classified into 4 main groups:

1. Vertical card files in standard sizes, 3 x 5 in., 4 x 6 in., 5 x 8 in., etc., with guides or markers dividing off and indexing the information.
2. Visible index systems, with vertically overlapping pockets or envelopes containing cards showing their successive margins on which the indexing notations, and often signals for control purposes, are placed. These systems may be filed flat or mounted vertically.
3. Visible index systems with horizontally overlapping cards so that the side margin may be used for indexing notations and postings. Such cards are filed vertically, as in ordinary card systems, and are usually placed lengthwise instead of crosswise of file drawers, to give more extensive top visibility. Long guides or markers index and divide off the various sections.

4. Rotary filing systems in which the cards are notched for mounting around the circumference of a large wheel or drum rotating within a cabinet and accessible for consultation or for the removal and replacement of cards on which typed or machine postings are made.

REGULAR CARD SYSTEMS.—Regular card index systems can be set up for many production control purposes. They are often used in purchasing departments for quotation, vendor, bid, commodity, and other records and indexes. Frequently they are used in stores records, or in storeroom location indexes. They may be used in engineering departments for indexing and cross-referencing parts and assembly drawings, bills of material, specifications, customers' orders, changes in drawings, patterns and pattern numbers, and other important data. In the production control department itself they are applicable to indexing and recording orders, operation sheets, route sheets, time study data, tooling for jobs, machine data, and other standard factors to which reference must be made. The extra time taken to locate information which must be constantly consulted, the extra work of removal for posting and then refiling, and the danger of losing separate cards which are not attached or keyed in to some system, are among the factors which have led to the abandonment of such card files in favor of the visible index form of record for a large portion of the work of production control.

VISIBLE INDEX SYSTEMS: VERTICAL OVERLAPPING.—The vertically overlapping systems of visible indexes are typified by Kardex, Acme, and a number of other designs, each having special features adapting it to the purposes to which it is applied. These systems are in wide use and are high in economy of time and space, easy for reference and posting, safe from the standpoint of loss or misplacing of cards or forms, durable, and effective for many kinds of production control work. The cards or forms are held in pockets which overlap each other in vertical rows.

The vertically overlapping pockets or cards have printed along their margins identifying data which place them in a proper position in a file which exposes these indexed or marked edges to view all at once. The cards are carried in holders provided with flexible hinges. When it is necessary only to consult the cards, the proper card can be located and the covering cards can be thrown back to reveal the full surface of the card needed. Posting can be done by hand or the card may be taken out and posted on a typewriter. In most cases the card is printed up specially for the company using the system, and is designed to fit the special needs and purposes in view. Control indexes or marker strips can be printed along the bottom edge of the card, showing items such as months of the year, days of the month, or any special entries such as "follow up," "begin operation," "final delivery date," etc.

Cards of this kind are often provided with transparent coverings over the index sections so that the cards are kept clean and do not become dog-eared or damaged. At the same time, by means of colored transparent markers of various types, such as the Kardex Graph-A-Matic signal, it is possible to provide checks or keys or other indications on important points. Among such marking points might be, in the case of inventory cards, markers to indicate reorder dates, markers to indicate when internal manufacturing orders for parts carried in stock should

Fig. 17. Production Control of Sales Orders

be placed in production, dates for purchase follow-ups, and many other indicators.

Applications of Visible Index.—The application of these cards to production control activities is illustrated briefly herewith by examples of actual installations showing the forms used, the purposes served, and the methods followed in keeping the records.

A simplified production control procedure is illustrated in Fig. 17, showing the form used by the I.T.E. Circuit Breaker Co. Cards are set up for each sales order to show the course of work for each item through essential operations. Completion of engineering work against promise, arrival of processed parts in the stockroom against promised dates, and the completion of assembling as compared with the scheduled date are recorded. A signal at the left over E, S, A shows where the order is at the time. The Graph-A-Matic signal at the right shows the date when the order is promised for completion.

In the Parish Pressed Steel Co., a copy of the production order is prepared on the foldover flap of an 11 x 9-in. buff Kardex form at the same time that the other necessary copies of this order are reproduced on a duplicating machine. The card (Fig. 18) is indexed by sales order, and is signaled by day and month when assembly is scheduled to start. If change orders are issued, they are made out on pink sheets which show through a small hole punched under "Amount" in the visible margin of the card. Entries of completions and deliveries are made in the shipping record and products scrapped or repaired are noted in the lower part of the card.

Blue cards (Fig. 19) placed below the order card are set up for each part to complete the order. If material is available, a signal is placed over the square marked "in stock" and the production order for the part is released. If material must be bought, purchase record entries are made on the card and production orders are held until the material arrives. When the material is released to the first operation, the signal is moved to the square "issued." Operation numbers appear along the right of the visible margin and the signal is moved over these numbers as the total quantity required is finished at each operation. The reports are entered in the operational progress record immediately above. Delivery of completed parts to the assembly line is entered in the upper left portion. Parts scrapped or repaired are recorded below.

VISIBLE INDEX SYSTEMS: HORIZONTAL OVERLAPPING.—A kind of record system having features particularly adapting it to production control purposes is typified by the Visirecord equipment (Visible Index Corp.). The cards are filed vertically and overlap horizontally across the file drawer. For easier reference and greater facility, these cards are usually filed lengthwise instead of across file drawers, particularly where they are kept in special large desks at which the record clerk sits. Index dividers and intermediate dividers are used to separate the different sections of cards wherever desired. Some 25,000 cards can thus be available within reach for consultation or posting without the operator moving from the desk chair. A desk telephone provides communication to and from operating departments which may receive and give information to go on the cards. Calculating machines enable

SCRAP RECORD

DATE	NO	TOTAL	DATE	NO	TOTAL	DATE	NO	TOTAL	DATE	NO	TOTAL	DATE	NO	TOTAL

REPAIRS RECORD

DATE	NO	TOTAL	DATE	NO.	TOTAL	DATE	NO	TOTAL	DATE	NO	TOTAL

S. O. NO.	CUSTOMER	AMOUNT
4772	A. B. Mfg. Corp.	4000

START FABRICATING

JAN FEB MAR APR MAY JUNE JULY AUG SEPT NOV DEC

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

Fig. 18. Form for Controlling and Recording the Progress of a Complete Order

SHIPPING RECORD
FROM
DATE
SHP'D
BAL.
FOLLOW UP RECORD
DEL'TD
SCRAP RECORD
REPAIRS RECORD
NO.
TOTAL

REMARKS

MATERIAL PURCHASE RECORD			
P O NO.	SUPPLIER	DATE PROMISED	DATE SHIPPED

MATERIAL REQUISITION RECORD					
DATE ISSUED	NO. SHEETS	SIZE OF SHEETS	CUTS	NO BLANKS	DATE DELIVERED

OPERATIONAL PROGRESS RECORD										
DATE FINISHED	NO PCS.	NO. PCS.	NO. PCS.	NO PCS.	NO. PCS.	NO PCS.	NO. PCS.	NO. PCS.	NO. PCS.	NO. PCS.

DRWG NO.	SYM.	PART	AMOUNT	ISSUED	IN STOCK	1	2	3	4	5	6	7	8	9	10
7935	A	Drain Pan	4000			5/14	5/19	5/24	5/28	6/6	6/10	6/14	6/19		

FIG. 19. Card for Recording the Manufacture of Parts for Order Shown in Fig. 18

LASTEX

PRODUCTION REPORT

DEPARTMENT

CODE

NO. MACHINES

PERIOD FROM TO

WEEK ENDING	DIRECT LABOR	MCH. HOURS	PRODUCTION		STD SPEED	ACT. SPEED		S/C HR.	A/C HR.	STD. COST PER YARD	ACT. COST PER YARD
			NET	GROSS		NET	GROSS				

"VISIrecord"—A PRODUCT OF VISIBLE INDEX CORP U S PATENT 1 973 558

Fig. 20. Visirecord Type Card (horizontal overlap) for Production Report

the operator also to figure any totals or values which it may be necessary to obtain from the data.

The cards, illustrated in Fig. 20 (8¾ x 10 in.), have visible triple margins. In most cases—unless a numerical record is involved—the cards are diagonally cut at 45° on either or both upper corners, usually for indexing. Wider margins are provided by longer corner cuts. The upper horizontal edge is provided with a series of heavy indicating signal blocks which automatically will indicate when a card is out. The cards rest on a ribbed corduroy base which gives them a footing. Offsetting of the individual cards is accomplished by a series of double notches on the bottom, fitting over spacer rods when the cards are down in place. Temporary stuffing is possible to bring like data on different cards together. Detailed data on operations, such as daily production quantities, can be posted to the columns normally covered on the card, leaving the visible side margin for totals. Down the side margin, therefore, there may be a complete history of the status of a job at successive operations. Various kinds of temporary or permanent signals can be applied to the cards. Progressive signals can also be applied on the diagonal or vertical margin of the cards.

The cards can be visibly utilized on both sides, if printed front and back, thus allowing more than one operator at a time to work on the trays or drawers.

ROTARY CARD FILE SYSTEMS.—To make large numbers of cards accessible in the quickest time and with the least waste motion, devices have been developed which find considerable application in the work of production control. Two typical kinds are the Wheeldex and the

M P C CARD
WHEELDEX FORM 10450

REMARKS:

SHOP ORDER	SERIAL	REQ	IN		DEPT	SHOP ORDER	SERIAL	REQ	IN	COMP	DEPT	TOOL	OPERATION	UNIT TIME	SET UP TIME

PART NO

MODEL

SECTION

FIG. 21. Rotary Card File System

Cardineer. Essentially, these consist of wheels or drums of suitable diameters to carry the required cards mounted in a framework or cabinet. The equipment is made in various sizes from smaller desk outfits up to units holding 6,000 to 8,000 cards, contained in a cabinet with casters for moving to desks, tables, or other workplaces. A cover protects the cards when not in use.

Cards are mounted by means of notches or frames on the circumference of the wheel or drum, which is then rotated to bring up the section in which any desired card is located (see Fig. 21). Dividers separate and index the various sections. Cards may be removed for typewriter, machine, or hand posting, and replaced readily. Hand posting can be done without removing the cards.

Gantt Charts

PRINCIPLE OF THE CHARTS.—One of the most comprehensive, condensed, and effective means for maintaining control of production is by means of Gantt charts. These charts, devised by Henry L. Gantt on the basis of many years of experience in a wide range of industries, make use of the two fundamental factors in scheduling, dispatching, and control—the **item** under consideration and the vital element of **time,** against which all production is really carried on. It is customary to list the items in a left-hand column, and to use the remainder of the sheet for the time ruling. The charts can be obtained from certain printers of forms and graphical material, or can be drawn up by the user. Generally they are printed on 11½ x 17-in. sheets and come punched and slotted at the right-hand side for filing in a post binder.

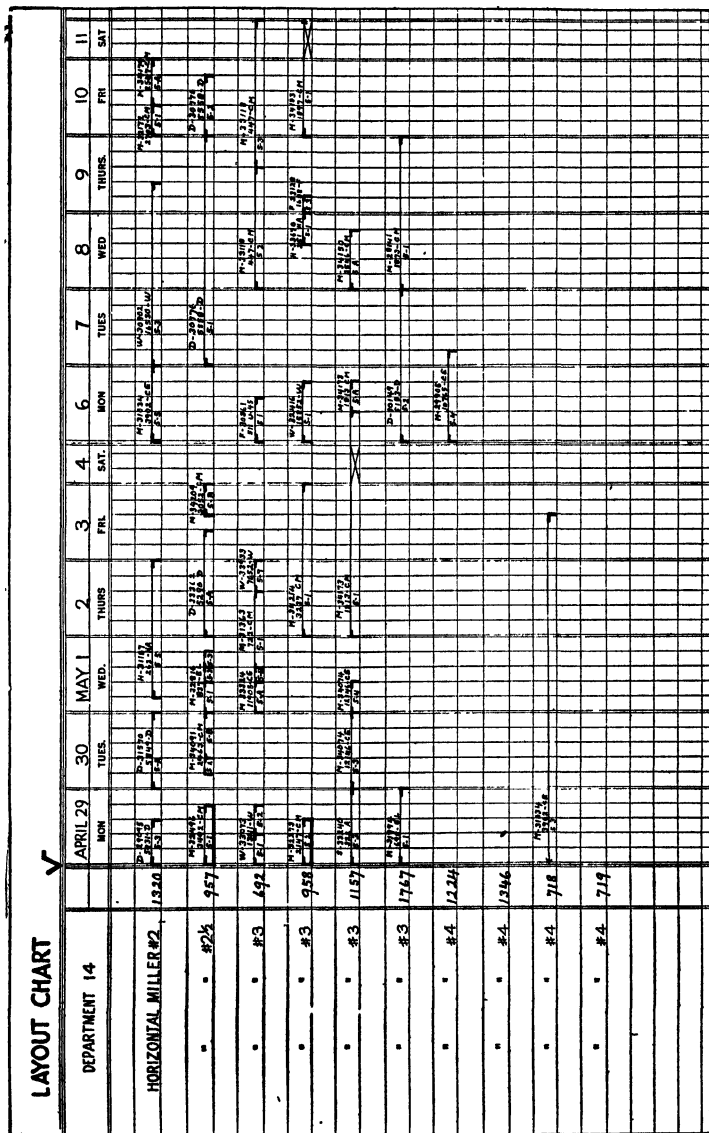
FORMS OF CHARTS.—There are five typical forms in which the chart is used:

1. Planning.
2. Load.
3. Machine idleness.
4. Man idleness.
5. Progress.

The first form can be used for the purpose of scheduling work on parts or assemblies, for determining inventory position and the time when replacements must be planned and started through, and for a variety of other planning purposes.

The load chart is used for the purpose of machine or workplace loading, including operations, subassembling, and assembling.

The machine idleness chart is special, on an 11½ x 17-in. sheet, and calls for the entry of time lost in machine delays, recorded in hours, by causes, or in some cases by dollars cost, by causes. The man idleness chart records time lost by workers, under the various causes. In both cases the useful time is plotted per machine or man as a percentage of the maximum available time.

Progress charts are used for recording the performance of work according to operations or entire sequences, or according to machine performance.

The planning, load, and progress charts, used for machine loading, and scheduling and recording the doing of work come in several varieties, but can be drawn in any form desired. The usual charts have 12 main divisions across the time ruling, thus providing for two 6-day weeks. These divisions may also be used to represent months, thus covering a year. These main time divisions are subdivided in various ways: five-period rulings for a 5-day week or a 10-hr. day, four rulings for an 8-hr. day, six rulings for a 6-day week or a 12-hr. day. Some charts come ruled for a 5½-day week. Others consist of the vertical rulings without subdivisions so that they can be divided in any way to suit the needs of the user.

MACHINE LOAD.—In many plants it is necessary to support any progress-of-work chart where orders are scheduled, by a detailed machine load chart where work is assigned to each machine or group of machines. Fig. 22 shows the assignment of work to each machine in the milling department. The angles connected by the light line designate the time of running each job which is represented by the symbols within the brackets. The daily space may be made large with divisions for hours shown, or small and without hourly divisions as the case may require.

COORDINATION OF PURCHASING AND MANUFACTURING.—In manufacturing many articles on a continuous basis, it frequently happens that some component parts are not made at the plant, but are purchased on schedule from outside sources. The two functions of purchasing and manufacturing may be conveniently coordinated by recording their progress on one chart so that each is shown in its proper relation to the other.

An example of such a chart is shown, in part, in Fig. 23. The first column shows the plant manufacturing order number, material or part name, and contractor when parts are purchased from outside. The second column contains the purchase order number, and the third column the number on order. It was desired to show the total number of parts which had been manufactured at the plant or had been received on purchase orders to date. Inasmuch as there was insufficient room to write the cumulative totals at the end of each weekly space, the first column of the time field was converted from its use as a time space into a column of figures showing the total number completed. Since these figures are changing each week, they cannot be entered in ink. Entering in pencil is unsatisfactory because the paper becomes worn out with erasing, and pencil records do not print clearly. Therefore, the figures are entered in ink on a separate strip of chart paper which is printed independently and pasted on the printed chart in the proper place.

On the first line is charted the **progress of the completed article,** and the title or stub, as it is called, is begun at the extreme left of the first column. The second line shows the progress of the bullets, which compose an assembly of parts. The stub here is indented from the left so that it appears beneath but not on a marginal line with the completed article of which it is only a part. Since bullets are made up of three independent parts—cores, jackets, and casings—stubs for these parts are still further indented so that they appear beneath the bullets but not on an equal margin with them. By such a method of marginal indenta-

CONTRACTS FOR AND MANUFACTURE OF ARMOR PIERCING AMMUNITION AND COMPONENTS

Work Order, Material & Contractor.	Purchase Order	No. on Order	Total No Completed	Week Ending May 4	May 11	May 18-	May 25	June 1	June 8	June 15	June 22
17M1758 Complete Rounds Loaded		900M	747,560	108M							
Bullets Complete Made at Plant		900M	858,357	102M							
Cores to Plant from S.G. Co.	1188 A	450M	450,000	Completed							
Cores to Plant from M.P. Co.	7597	200M	82,875	Completed	Short						
Cores to Plant from M.F. Co.	7000	250M	250,500	108M							
Jackets Made at Plant		900M	1,100,193	108M							
Casings Made at Plant		900M	868,650	108M							
18M 285 Complete Rounds Loaded		7,500M	62,250						100M		
Bullets Complete Made at Plant		3,500M	81,007					102M			
Bullets Complete from M.S. Co.	13,275	4,000M	0								
Cores to Plant from S.G. Co.	9,853	3,500M	385,000					108M			
Jackets Made at Plant		3,500M	264,004					108M			
Casings Made at Plant		3,500M	255,873					108M			

FIG. 23. Gantt Progress Chart Coordinating Purchasing and Manufacturing

tions, or "brief" form, a complex assembly may be arranged for charting so that all parts are seen in their proper relation to each other.

The lower group of stubs is a repetition of the upper group, but is for a different work order laid out to follow the first. The **weekly schedule** is written in the first space and does not appear again because the same schedule continues throughout the chart. **Weekly performance** is shown by light lines. Their length indicates the percentage of the week's schedule fulfilled. The heavy lines are the cumulative or progress lines and are equal to the sum of the light lines. Bullets for a part of this order are being made at the plant, for which cores are purchased from outside, and jackets and casings made at the plant. In order that manufacture may be kept up to schedule, these three parts must be up to date. The date is indicated by a "V" at the top of the chart placed at the end of the week through which the chart is posted. **Assembling** of the completed bullet necessitates withdrawing from stores the cores, jackets, and casings which are parts of the bullet, therefore the progress line of the completed bullet represents also the consumption or used line for the component parts. Since the bullet and its component parts begin at the same point of time, the difference in the length of their heavy lines, and hence the amount on hand, can be read by the difference in the position of the ends of the lines. Each component line must be referred to the bullet progress line.

CONTROL OF MANUFACTURE OF PARTS ON ORDER.—A chart for controlling manufacturing on order, where each customer's order is planned and executed independently of any other order for like material, is illustrated in Fig. 24. The method is here applied to a few selected parts entering into the manufacture of a fuse, and in principle is the same as Fig. 23.

The weekly columns are divided into six spaces to permit daily posting, and the system of marginal indentations is used to distinguish between components and assemblies. The numerals on the bars stand for **manufacturing operations,** and their location on the time field indicates days on which the operations should be started. An angle and a numeral 1 indicate the day on which the first operation is to start, and operations 2, 3, 4, etc., are to start on days designated by their location in the daily spaces. When the first operation is started the heavy progress line is drawn half-way across the daily space, and when the second operation is started the bar is drawn half-way across the daily space indicated by the numeral 2. When all of the operations are started there is a series of broken bars whose lengths mean nothing, but simply indicate that work has commenced on these operations. When the full number of pieces have passed through an operation, the bar is drawn through that space to connect with the next portion, so that ultimately when all operations are completed there is a continuous bar.

The **completion of parts** is shown by the solid portions of the bars, which commence at the dates of the respective final operations, and which are extended each day to record the amount of work done as measured by the daily schedule.

Assembly of the fuse is shown on the first line, and the schedule calls for 1,000 per day. Delivery of completed units is planned for October 8, where the ninth and last operation in the assembly is recorded, and is to

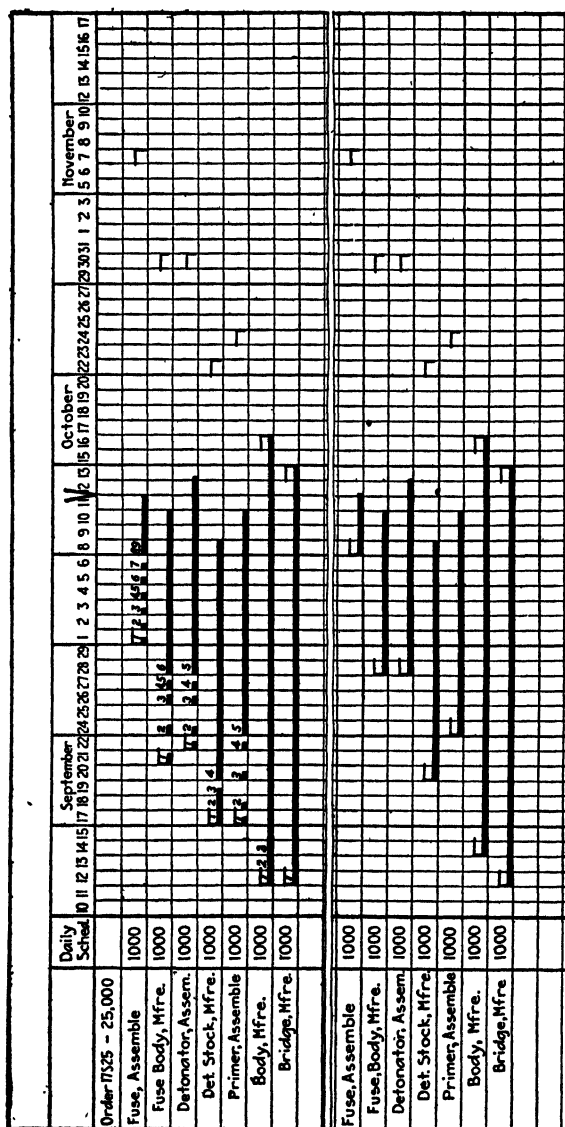



Fig. 24. Gantt Progress Chart for Control of Operations

continue at the scheduled rate until the order is completed on November 7, counting Saturdays as half-days. Working back from the ninth operation, it is seen that the first must be started on October 1. Before the first operation can be started, two of the major components, the fuse body and the assembled detonator, must be ready, so their final operations are planned for September 28. This provision allows a leeway of one and one-half working days for the accumulation of a reserve stock of these two parts before they will be withdrawn for the fuse assembly. Since these are parts of the fuse, they are listed with a marginal indentation. Similarly, the assembled detonator is made up of a detonator stock and an assembled primer, so these two parts are given a further marginal indentation under the line "Detonator assemble." No work may be performed on the detonator assembly until stocks have been made, so that the fourth and last operation on the stock is planned ahead of the first operation on the assembly, and the primer is planned so that it will be ready when needed in the detonator assembly. In a similar manner the primer body is shown as a part of the assembled primer, and the bridge as a part of the body

The lower portion of Fig. 24 depicts a more **abbreviated method of showing progress,** where individual operations have been omitted and the initial brackets placed to show when deliveries from the final operation on each part or assembly are to begin.

Completion of fuse bodies must commence on September 28 if the assembling operations are to proceed on time and reach delivery of fuses on October 8. The fuse-body bar between these two dates designates two things: First, that portion between October 1 and 8 represents the amount of bodies which is needed at a given time in the process of assembling the fuses; and second, the portion between September 28 and October 1 represents the amount which is considered necessary as a reserve stock.

The sum of these two portions, or that section of the bar appearing between the two starting brackets, represents the minimum quantity which is needed between the last operation on the fuse body and the last operation on the fuse assembly if uninterrupted assembly is to be maintained.

The total length of the body bar represents the number of bodies that have been made, and the fuse-assembly bar represents the number of completed fuses. Inasmuch as completed fuses must have bodies in them, the difference between the lengths of these two bars represents the number of bodies which are actually in the assembly process and in stores. If the end of the body bar is abreast of the fuse-assembly bar, the difference in their total lengths is exactly that section of the body bar lying between the two starting brackets which, as already demonstrated, is the minimum amount needed for ideal operation. If the end of the body bar is behind the fuse-assembly bar, the difference in their lengths is less than the section of the body bar lying between the starting brackets by an amount equal to the difference between the ends of the two bars. This is the amount by which the bodies in the assembly process and in stores fall short of the required minimum.

On the other hand, if the body bar is ahead, the amount by which it projects beyond the end of the fuse-assembly bar indicates the quantity of bodies in assembly and stores in excess of the required minimum.

Consequently, in reading the chart it is necessary only to **compare the relative positions** of the ends of the two related bars in order to determine the number of days behind or ahead of schedule the production of the component part may be. For balanced operation all bars will be abreast of the assembly bar, and if production has been progressing at the scheduled rate, all will be abreast of the current date, October 12, indicated by the V on the time scale along the top of the chart.

CONTROL OF MANUFACTURE OF PARTS FOR STOCK.— The case of continuous manufacture for stock presents a somewhat different problem. It is not a case of charting the future plan of parts and assemblies to be made on order, as described above, but it involves charting production of parts now being made for stores, and the continuous production of machines now being assembled for stock. It must be a cross-section of the current manufacturing position. Application of the Gantt Chart to this situation was devised by Porter and is described as follows:

The first step is to take the balance in stores of each part and add to this the respective numbers in subsequent assembling operations. The result is the true inventory figure of each part. If this inventory were charted so that all bars started at the inventory date, we should have a stock chart. This has been done for the first group of parts shown in Fig. 25. However, the stock chart is not satisfactory for controlling production, for it shows neither the true manufacturing position of the parts with one another nor with the current date. Since the stock condition is constantly changing, the whole chart would have to be redrawn each time the new conditions were charted.

Fig. 25 illustrates the **development of a stock chart into a progress chart.** For the sake of simplicity only three parts entering into the completed machine, "boxed," are shown. The marginal indentations indicate that the forging is a part of the shaft, the shaft a part of the bowl, etc. The column headed "Min./Wks." refers to minimum time in weeks or amount of parts needed for the succeeding operations in assembly and for a safe margin of the stock. This amount is determined in a manner similar to that used for the fuse. The third column gives the weekly schedule. The **first group of broken bars** at the top of Fig. 25, as already mentioned, represents the stock on hand and parts in process at the end of the week of July 14. For example, the shaft bar represents the number of shafts in the storeroom plus those in process of being assembled into bowls. Inventory figures are carried at the extreme right for reference during this discussion; they are not ordinarily incorporated in the chart.

The **second group of bars** shows the same data with a different arrangement in regard to time. The starting bracket for the boxed machine remains fixed at the date on which the inventory was taken. Inasmuch as the bowl is a part of the completed machine and there should be a minimum reserve of one-half week, the initial bracket of the bowl bar should be placed that amount behind (to the left of) the starting bracket of the boxed machines. If there had been any boxed machines, the bowl bracket would be placed one-half week behind the end of the bar representing the boxed machines. It is seen that there are just enough bowls in stock to fill the one-half week's reserve, which brings the ends of this

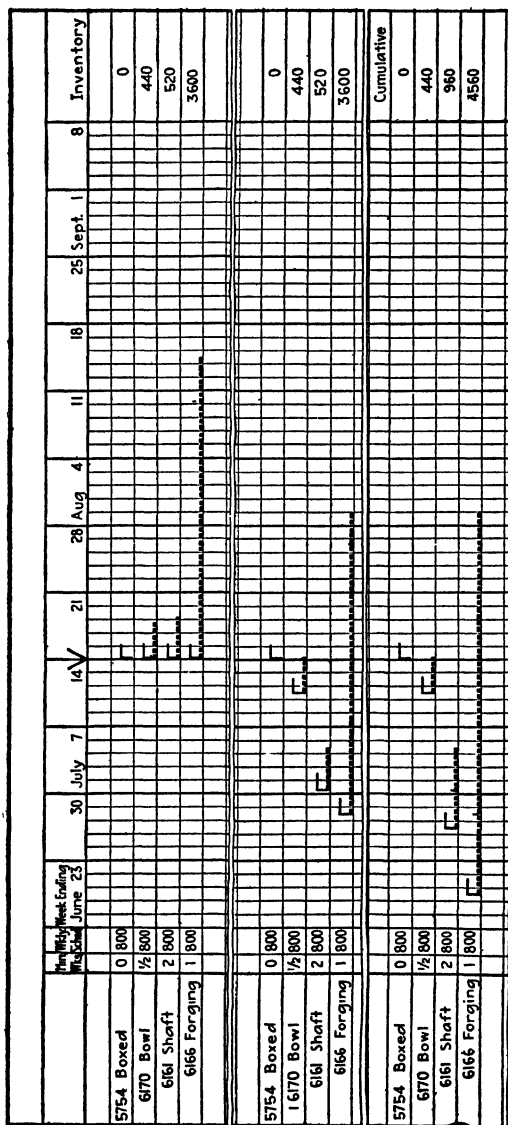



Fig. 25. Development of Progress Chart from Stock Chart

bar abreast of the inventory date. Since the shaft is a part of the bowl, and a two weeks' reserve is needed, the 520 not yet assembled into bowls should be represented by a bar commencing, not at the inventory date, but at a point two weeks in advance of where the bowl bar ends. Similarly, the forging is a part of the shaft, and its bar should commence one week ahead of the end of the shaft bar. Ends of these three bars now show their correct position with reference to the date of posting on July 14. The shafts are 1.3 weeks behind and the forgings are 2.2 weeks ahead of schedule.

The **third set of bars** is a further refinement which concerns the position of the starting brackets. It is desired to have the time interval between the starting brackets of two related parts indicate the minimum reserve required. That is, if there should be two weeks' reserve of shafts, the shaft starting bracket should be two weeks ahead of the starting bracket for the bowl bar. To do this it is necessary simply to add the number of bowls to the number of shafts and carry the total back from the end of the shaft bar already determined. This total is then added to the forgings, and the cumulative result is projected back from the end of the forging bar. The bars are now true **progress bars** which show how many parts have been made and whether they are ahead of or behind schedule. They have exactly the same meaning as the lower group of bars in Fig. 25.

The **amount of stock** also may be read from this chart. Since the forging bar now represents the total number of forgings made, and the shaft bar immediately above it is a total of shafts and bowls which contain forgings, the difference between the two bars is the number of forgings in stock and in process. That portion of the forging bar extending to the left of the shaft starting bracket is the minimum reserve, and that portion extending to the right beyond the end of the shaft bar is the amount on hand in excess of minimum requirements. This relationship will hold true with the addition of each week's production, because shafts are made at the expense of forgings; that is, for every shaft made a forging must have been used out of stock. Therefore each bar represents consumption of parts which are components of it as well as the production of the part for which it stands. Right-hand ends of the short bars are referred to the posting date in order to determine what work is behind schedule, while left-hand ends of the longer bars indicate when parts will have to be started in production again. Also, the end of any bar is referred to the corresponding end of the bar which represents its consumption—that is, the part of which the part in question is a component—in order to determine the amount of stock on hand and in process.

Fig. 26 is **further application of this method** to the bowl and shaft, which are two of the major assemblies entering into a separator. There are two sizes of machines shown, with some parts that are individual to each and others common to both. The marginal indentations indicate the arrangement of the parts and make it possible to compare the production and consumption bars for any part. The procedure for laying out these bars is reduced to a simple formula. The bracket for the boxed machine is entered at the date when inventory is taken. Since the bowl is a part of the boxed machine, its bracket is entered one-half week in advance, as indicated by the minimum week's requirements. The broken bar is

Week Ending: July 21 | 28 | Aug 4 | 11 | 18 | 25 | Sept 1

Part No Name	Min Wks	Wkly Sched	Inventory
5753 No. 10 Boxed	0	300	0
6160 Bowl No 10	½	300	150
6164 Shaft	2	300	960
6151 Forging	1	300	2,010
6181 Bushing	1	300	180
6165 Shell	1	300	1,110
6162 Stamping	1	300	+3. 2,490
6152 Dist	2	300	+1. 3,000
5754 No 12 Boxed	0	800	0
6170 Bowl No 12	½	800	440
6161 Shaft	2	800	520
6166 Forging	1	800	3,600
6182 Bushing	1	800	4,000
6167 Shell	1	800	2,600
6168 Stamping	3	800	3,000
6163 Dist.	2	800	4,800
Com to Nos. 10-12 Bowl	½	1100	590
6107 Int Disk	1	36,000	144,000
6109 Top Disk	1	1100	1,210
6108 Disk	2	1100	5,600
6117 Lug	1	1100	3,500
6110 Wing	1	3300	19,800
3015 Cr Sc	1	1100	6,000
Com. Nos 10-12 Shaft	2	1100	1,480
6106 Bowl Nut	2	1100	400
6144 Driv Dog	1	1100	5,800
6111 Cr Pin	1	1100	6,500
6145 Bushing	1	1100	6,900
6114 Loc Pin	1	1100	7,500

FIG. 26. Gantt Progress Chart for Bowl and Shaft of a Separator

drawn to represent the amount of bowls in stock plus those in process of being assembled in boxed machines. Since the shaft is a component of the bowl, its starting bracket is entered two weeks ahead of the bowl bracket, and the bar is drawn to represent the number of shafts in stock plus those in process of bowl assembly plus the amount already found for bowls. In this case it would be 960 plus 150, or 1,110. The forging bracket is placed one week ahead of the shaft, and its bar will be 2,010 plus the previous total of 1,110 units in length. The bushing is seen to be a part of the shaft, not a part of the forging; consequently its bracket is placed one week ahead of the shaft bracket, and its bar is 180 plus 1,110 units in length. The shell is a part of the bowl, so its bracket is placed one week ahead of the bowl bracket, and its bar represents 1,110 plus 150, or 1,260 units. The stamping, being a part of the shell, begins one week ahead of the shell, and its bar is 2,490 plus the previous 1,260 units in length. This bar extends beyond the field of the chart, and the number of weeks is indicated by the numeral 3.

The same procedure is followed for those **parts that are special** to the No. 12 machine. The parts that are common to both bowls are arranged beneath the line with that designation. This "common" bar starts even with the two bowls, and its length is determined by the sum of the two bowls in stock and in the assembly process divided by the combined schedule of both, or 150 plus 440 divided by 1,100. The parts common to both shafts are treated in the same way. Their "common" bar begins two weeks ahead of the "common" bowl bar, and the length is determined by adding the total of both shafts in stock and in the bowl assemblies to the previous total for bowls and dividing by the combined schedule, or 960 plus 520 shafts plus the 590 bowls divided by 1,100.

This chart shows at a glance that the bowl nut is over two weeks behind and is consequently holding up the production of shafts. It also shows that other parts are quite far ahead of schedule and do not require any production activity until the bar of finished machines has caught up with them. For example, if the production of finished No. 10 machines keeps up with the schedule, then production on the No. 6151 forging will have to be resumed during the week of September 1. If the production of completed machines lags behind schedule, production of forgings will not have to be resumed until the bar for finished machines draws abreast of the forging bar, no matter what the calendar date may be at that time.

Fig. 27 shows the **method of posting production.** The amount of production each week is represented by the light lines appearing within the corresponding weekly spaces. The heavy solid bar cumulates the production throughout the weeks and shows the total number made from the date the inventory was taken. It is seen that this chart is maintained by posting only the production of parts, or the receipts into stock, and does not require the double work of posting withdrawals from stock. This result is accomplished by making each line serve the double purpose of representing production of its own part and the consumption of those parts which are components of it. This procedure is made possible by the arrangement of parts in marginal steps as already explained. All lines should keep abreast of the current date as with soldiers marching "company front." The one out of step or lagging becomes the exception

Part No. Name	Min. Wks.	Wkly. Sched.	Week Ending				July 21	28	Aug 4	11	18	25	Sept 1	
5753 No. 10 Boxed	0	300												
6160 Bowl No 10	1/2	300												
6164 Shaft	2	300												
6151 Forging	1	300												
6181 Bushing	1	300						5						
6165 Shell	1	300												
6162 Stamping	1	300												+3. Wks.
6152 Dist	2	300												+1.
5754 No 12 Boxed	0	800												
6170 Bowl No. 12	1/2	800												
6161 Shaft	2	800												
6166 Forging	1	800												
6182 Bushing	1	800						375						
6167 Shell	1	800												
6168 Stamping	3	800												
6163 Dist	2	800												
Com. Nos. 10-12 Bowl	1/2	1100												
6107 Int. Disk	1	36,000												
6109 Top Disk	1	1100												
6108 Disk	2	1100												
6117 Lug	1	1100												
6110 Wing	1	33,000												
3015 Cr Sc	1	1100												
Com Nos 10-12 Shaft	2	1100												
6106 Bowl Nut	2	1100												
6144 Driv Dog	1	1100												
6111 Cr Pin	1	1100												
6145 Bushing	1	1100												
6114 Loc Pin	1	1100												

Fig. 27. Method of Posting Production

from the rest and is made conspicuous. It is this feature of all Gantt charts, which renders conspicuous any exceptions to plan, that makes it such a valuable tool for control. It fulfills the law of exceptions as proposed by Alford (Laws of Management Applied to Manufacturing), which is: "Managerial efficiency is greatly increased by concentrating managerial attention solely upon those executive matters which are variations from routine, plan, or standard."

Knowledge, not opinion, must be the basis of all intelligent action. The chart organizes, coordinates, and presents facts so that knowledge may be substituted for opinion, and it also serves as a measure of executive skill.

DETAIL ORDER LAYOUT.—Fig. 28 is a detail progress chart of orders and production. The same printed form is used with the addition of columns ruled by hand at the left to suit the particular requirements. The total schedule for all orders of No. 1 quality fine is 178 lb. per week, which is written across the top of the chart. The row of figures directly beneath is the allotment of orders against schedule. Orders are listed as they are received and are laid out by angles to commence in the first week which has not already had its quota assigned to it. Progress on the orders is shown by heavy bars. Each bar is extended at the rate indicated by the schedule of its order.

\#1 QUALITY FINE

Size	Date	Order No	Am't.	Previous to Oct 3	Oct 8	Oct 15	Oct 22	Oct 29	Nov 5	Nov 12	Nov 19	Nov 26	Dec 3	Dec 10	Dec 17
					178 178	178 178	178 178	178 178	178 228	178 218	178 179	178 175	178 178	178 157	178 150
30/3	Jul 15	3524	50	12	38										
40/2	" "	3527	100		25	25	50								
60/2	" 19	4509	500	500											
40/3	Aug. 2	3532	100	100	Surplus Stock to be applied										
33/3	" "	3535	100	50	25	25									
36/2	Sep 7	3547	250	40	50	50	50	60							
1600	" 12	3548	63		25	38									
28/3	" 19	3552	58		15	40	3								
23/3	" 20	3553	50				25	25							
36/2	" 29	3556	50				25	25							
23/3	Oct 3	3559	50				25	25							
27/3	" "	3561	50					43	7						
60/2	" "	4533	65		Stock Order					41	Closed	Short			
33/3	" 13	3565	8						8						
42/2	" "	3566	25						25						
23/3	" 18	3567	175	At once					113	62					
40/2	" 21	3568	100							100		Shipped Dec. 14			
54/2	" 25	4545	25	Nov. 1					25						
40/3	" 28	3569	50						50						
36/2	Nov 2	4551	50	Take out all that is in Stock to help Fill						15	0	0	28	7	
48/2	" "	4552	4	Nov. 19 sure							4				
23/3	" 3	3573	200	Soon as possible		Shipped Dec 13					75	75	50		
40/2	" "	3574	150								50	50	50		
60/2	" "	4554	150								50	50	50		
40/2	" 17	3581	250	After Order 3574										50	50
36/2	" 16	3580	150											50	50
23/3	" "	3579	100											50	50
50/2	" 21	4562	12												

Fig. 28. Gantt Detail Progress Chart for a Single Product

Punched-Card and Tabulating Systems

MECHANICAL PUNCHED-CARD SYSTEMS.—There are many mechanical systems available for controlling and facilitating production, inventories, cost, and other elements of plant operation, including those of the International Business Machines Co., Remington Rand, and others. The International Business Machines system is typical. It consists of comprehensive methods based upon the use of punched cards and card-operated accounting machines for the recording and control of all production from the formulation of the executive master manufacturing budget to final assembly of the products. The company adapted this method to its own organization for the control of manufacturing activities

CHARACTERISTICS OF MANUFACTURING TO WHICH APPLIED.—The characteristics of manufacturing in this company, as stated in the company's manual on "Production Control," are:

1. The dual problem of manufacturing to special order and filling orders for stock.
2. Wide variety of finished products in many models.
3. Large variance in sales demand for different products
4. Finished products composed of many parts and assemblies.
5. Parts that are common to more than one product. Almost 60% of the parts are interchangeable between two or more products.
6. Extremes of processing time for different parts.

At the time this procedure was adapted the company manufactured seventy classes of equipment in over six hundred models. These products were made in over 1,600 different variations Manufacture requires 8,000 items of raw materials and approximately 72,000 different finished parts. Some 58,000 of these finished parts are manufactured and the other 14,000 are purchased from outside vendors.

The Master Planning Budget.—The sales estimates are prepared on a monthly basis covering each major product, according to expected sales. The monthly production program starts with an analysis based on the last 4 months' record. The executive committee specifies the quantity of each item to be produced based upon the sales forecast, unshipped orders, stock now on hand, and open production orders in the manufacturing plant.

BREAKING DOWN REQUIREMENTS.—The manufacturing planning program begins with breaking down the sales forecast into the detailed subassemblies, parts, operations, and raw materials required. Punched-card accounting machines serve this purpose.

A production explosion chart (Fig. 29) is plotted showing, for a manufacturing unit, first, the breakdown into major assemblies and separate parts, and then at each subsequent successive step the further breakdown into subassemblies and parts.

Assembly Planning.—Based upon this "explosion system" the parts requirements for all assemblies and subassemblies are determined before any parts manufacturing orders are initiated. The assembly planning is

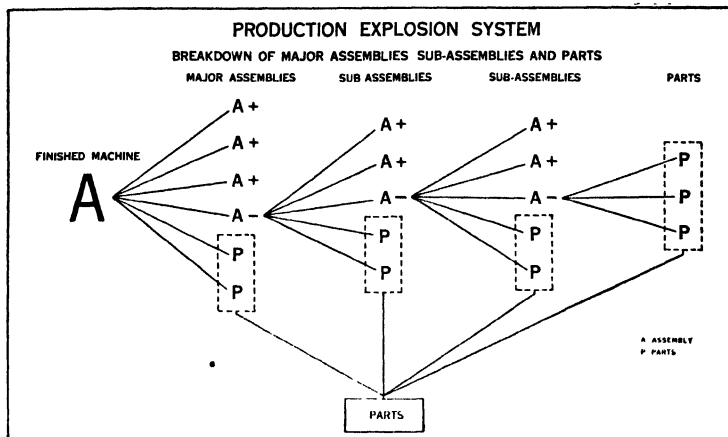



Fig. 29. Chart of Production Explosion Method

facilitated by the use of two types of punched cards—the bills of materials specification, and the inventory transaction records.

The Master Control Files (Assembly Bills of Materials Specifications).—Cards are prepared for each part used in an assembly (Fig. 30). This file consists of a complete set of component parts specifications for each assembly or subassembly manufactured. It serves as a means of automatically preparing parts requisitions, stock reservations, and bills of material (Fig. 31). A parallel file of "labor operation" master cards (Fig. 32) is maintained for each element appearing on a routing sheet. Whenever an assembly order is issued, the corresponding group

HOW USED	COST	DAYS	MFG QUAN	STOP TAG	PART NO	PART NAME
3 +	5			ON / OFF	128291	CARBON RIBBON FEED

USED ON	405
QUAN	1
USED ON	
QUAN	

MINIMUM RESERVATION

PART NO	ORDER NO	DATE ORDERED	QUANTITY ORDERED	QUANTITY RECEIVED	DATE RECEIVED
128291	1115	8 15	50	50	8 25
128291	1231	9 12	50		

LICENSED FOR USE UNDER PATENT 1772492

Fig. 30. Production Control Master Card

BILL OF MATERIAL

QUANTITY: 50 | DATE ISSUED: | ORDER NO — PART: 128291 SEQ: 1231

GROUP NAME: CARBON RIBBON FEED CORR LIST | DWG NO | NO OF SHEETS 1

DESCRIPTION		PART NO	QUAN ISSUED	STOCK LOCATION	NO PER UNIT
REMOVE					
CARD FEED TOP SIDE COVER		124864			1
PLATEN PRESSURE SPRING		141614			1
MTG SCREW WASHER		16673			4
ADD					
OPER LEVER STUD NUT		22354			1
LEVER STUD LOCKWASHER	DNF	37073			1
COVER MTG SCREW	DNF	38380			2
OPER LEVER LINK ASM CLIP	DNF	60489	•		2
UNIT ASM MTG SCREW		77086			4
RIBBON FEED MECH ASM		128201			1

Fig. 31. Bill of Material Tabulating Machine System

of specification cards is selected from the file and used to create automatically the required documents. The reservation cards reflecting this planning are placed in the perpetual inventory file.

The Perpetual Inventory File and Stock Status Summary.—The perpetual inventory punched-card file contains transaction records covering open orders, reservations, requisitions, deliveries-to-stock, and miscellaneous transactions such as scrap, credit requisitions, etc. At the time of assembly planning, the assemblies for which planned usage (reservations) occurs are selected from the file, and tabulated automatically to prepare a stock status summary (Fig. 33) to reflect the availability of these assemblies. If the available balance is insufficient, a new assembly

12 | 120615 | 151 | 5 | 98 | 4 12
F
S
LB R. 541645
LICENSED FOR USE UNDER PATENT 1,772,492

Fig. 32. Labor Card

order is originated. The stock summary shows **what** to order and conventional history records in the production control department show **how many** to order and when the material must be delivered to stock. The final tabulation of this file is the basis for issuing parts manufacturing orders. If the part is purchased, the history file is referred to and the purchase requisition is originated.

OPERATION RECORDS.—The operation record is automatically printed from prepunched labor operation-planning cards (Fig. 32), two copies being prepared, one a control copy and the other a factory copy (Fig. 34). On the operation record the following data are entered: order number, department charged, quantity, date issued, part name, operation, operation number, department number, tool number, group number,

STOCK STATUS SUMMARY

COST CODE	C_H L_U	PART NAME	PART NO	AVAILABLE	IN STOCK	ON ORDER	CONSUMPTION	FIELD CONSUMPTION
6	51	MOUNTING PLATE	110002	1328CR	2472		8338	
3	51	CAM ARM STUD	110003	337CR	2663		8571	4
3	51	BAIL ARM STUD	110004	671	226	5000	11661	5
3	51	KNOCK OFF STUD	110005	3131	5183	984	8662	
3	51	ARMATURE STUD	110006	596	596	3000	8466	
3	51	TRIP STOP STUD	110007	3196	6196		8403	30
3	51	STUD	110008	3112	3112	3000	8717	6
1	51	SPRING STUD	110009	715	3715		8375	
1	51	SPRING STUD	110010	1021	4521		8389	
[illegible]	51	LATCH STOP	110011	1491CR	1509		8928	620

FIG. 33. Stock Status Summary Prepared from Punched Card

scheduled date, machine number, man number, date, total number of pieces, and "sent ahead," the latter when runs are split so that the first lots may be moved through in advance of other lots.

Labor cards (Fig. 32) are prepunched for each operation on each part and are summarized to prepare the necessary shop load input reports, after which the cards are sent to the shop departments.

DISPATCHING.—The cards are held in the shop inactive file until the raw material or parts arrive on the department floor, at which time they are transferred to the active file. When an employee starts a job, the corresponding labor card is pulled from the active file, time-stamped, and placed in the "jobs working" rack, where it remains until the job has been completed and the finish time has been stamped on the card. The shop clerk notes on the card the employee number, elapsed time, pieces, etc., and sends the card to the payroll department.

The file of active and inactive labor tickets is picked up from a shop department and the machine-hour load reports (Fig. 35) are tabulated weekly. The production manager and the foreman can then see what work is scheduled ahead on each machine group in each department. The reports also show when certain machine groups are going to be over-

OPERATION RECORD — FACTORY COPY

← CARBON COPY

ORDER NO		DEPT CHG		QUANTITY
120615	115			500

PART NAME
GEAR STUD

OPERATION	OPER NO	DEPT NO	TOOL NO	GROUP NO
RAW STORES				
H S TURN 3 SHLDRS ROUND END THREAD CENTER AND CUT OFF				
MILL SLOT				
H S TURN O D AND CTR OTHER END				
BURR O D SLOT EDGE				
GRIND O D 5903 DIA				
GRIND O D 3745 DIA				
INSPECT AND OIL				

OPERATION RECORD — CONTROL COPY

ORDER NO		DEPT CHG		QUANTITY		DATE ISSUED	
120615	115			500			

PART NAME
GEAR STUD

OPERATION	OPER NO	DEPT NO	TOOL NO	GROUP NO	SCHED DATE	MACH NO	MAN NO	DATE	TOTAL NO PCS	SENT AHEAD		
RAW STORES	1	50										
H S TURN 3 SHLDRS ROUND END THREAD CENTER AND CUT OFF	5	5	876942	98							3	9000
MILL SLOT	10	1		4								3400
H S TURN O D AND CTR OTHER END	15	5		98								6100
BURR O D SLOT EDGES	20	4		102								1500
GRIND O D 5903 DIA	25	7		117							1	6000
GRIND O D 3745 DIA	30	7		117							1	3000
INSPECT AND OIL	35	40										

Fig. 34. Operation Record

MACHINE HOUR LOAD

DEPT. ONE — MONTH OF JULY 19—

GROUP	ACTIVE HOURS	INACTIVE HOURS	TOTAL HOURS	WEEKLY CAPACITY	NO OF WEEKS COVERED
1	1236	7908	9144	704	13 0
					2 0
					12 4
					16 3
					32 5
					20 4
					6 7
					4 7
					23 2
					35 2
					43 3
					46 8

MACHINE HOUR LOAD
SUMMARY BY DEPARTMENT

MONTH OF JULY 19—

DEPT	ACTIVE HOURS	INACTIVE HOURS	TOTAL HOURS	WEEKLY CAPACITY	NO OF WEEKS COVERED
1	5535	38191	43726	2304	19 0
3	9793	51730	61523	2816	21 8
4	1340	26019	27359	1856	14 7
5	6900	5149	12049	992	12 1
7	2638	33346	35984	1440	25 0
8	14339	11100	25439	1472	17 3
15	14682	8598	23280	2048	11 4
	55227*	174133*	229360*	12992*	

Fig. 35. Shop Input Load Report Printed from Punched Cards

loaded so that steps can be taken to avoid such a condition. Likewise, idle periods are disclosed, so that routine work or manufacture for stock can be utilized to fill up the gaps. The foreman can see currently what jobs should be pushed and which are on schedule.

Duplicating and Communication Equipment Systems

PARTS ORDER SYSTEM.—Duplicating equipment is of vast service in cutting down the large amount of clerical labor and writing otherwise required in many well-organized production control systems. Reductions of 60% in labor and 90% in writing are common. In the Hamilton Manufacturing Co., among other plants, the Ditto system is employed for parts orders. A production order master form is prepared from the operation lists and routing for a part, and is filed by part number. When the part is to be run, this master is used and, through Ditto carbon on a separate superimposed variable master form, there are written in longhand the necessary specific data, such as order number, quantity, etc. These two masters are then reproduced to give production orders going to each department doing the work, and to the planning department (Kardex copy) and dispatcher. (See Fig. 36.)

Unit cards are then reproduced, without rewriting, for each single operation (only) plus the data from the head of the master. These cards are a move ticket, standards and instruction card, board ticket and inspection record, and group bonus record (Fig. 37). The dispatcher receives a copy of the production order and the control copy of the board ticket and inspection record, the latter of which he files under the completion date for the department doing the operation.

The department foreman receives a copy of the production order, a standards and instruction card, and a move ticket, filing the latter two in the "Jobs Not Here" rack under the date when the preceding operation is scheduled to be completed. If the work does not come along on time, he sends the standards and instruction card to the dispatcher to get a new date for the operation. When the work does arrive, the cards are moved into the "Jobs in Process" rack under the stated completion date. After the job is done, the foreman sends the standards and instruction card to the dispatch station, where the dispatcher moves the board ticket and inspection record from the operation rack to the inspector's rack.

The inspector records on the inspection ticket the number of good pieces and rejects and returns the card to the dispatcher, who forwards it to the planning department for entry on the production order. The

Order Number: 1 f1848-5 — Date Issued — Quantity: 200

	Std for Lot	Schedule
P	17180	10/12
O	695	11/2
N	1002	11/3
M	4965	11/8
L	22630	11/2
K	1765	11/2

Order Number — Quantity — Article Name: PLANFILE UNIT — PRODUCTION ORDER — Article Number: #1848 — Detailed by — No. of Cards — Blueprints: 1848-XA 1830-X 1830-XB — Steel Detail: 3 — Lumber Req'n — Move Tickets

	Std for Lot	Schedule	Performance	Dept	Operation Routing	B	Move to Dept
P				21	SHEAR		21
O				21	CUT AND GRIND RODS		25
N				21	PRESSWORK		21
M				21	PUNCHING		21
L				21	BEND		20
K							

FIG. 36. Production Order Master Form for Duplication Showing Superimposed Variable to Left

work is sent to the next operation with the move ticket. The group bonus record form (Fig. 38) is used for calculating the worker's earnings and bonus.

ASSEMBLY AND SUBASSEMBLY ORDER SYSTEM.—In the plant of the National Supply Co., a bill of materials master form is typed through Ditto carbon for each subassembly or assembly as it is set up, and is filed by assembly number. When an assembly order is to be put through, this master form, combined with a variable master, separately typed and superimposed (Fig. 39), is used to make a production office copy and scheduling department copy (Fig. 40) and unit requisition gummed 15 to a set (Fig. 41). After separation, the unit requisitions are sent to the scheduling department where they are filed by schedule date. On this date they are sent to the storeroom for delivery of parts to the assembly department.

The production office and scheduling copies of the order, reproduced on blank stock, are used for departmental records and follow-up.

PRODUCTION ORDER SYSTEM.—In a system used by the Addressograph Multigraph Corp. and employing Addressograph plates to

ORDER NUMBER J1848-5
ARTICLE NAME PLANFILE UNIT
MOVE TICKET
ARTICLE NUMBER #1848
QUANTITY 200
BLUEPRINTS: 1848-XA 1830-X 1830-XB
STEEL DETAILS 3
LUMBER REQ N.
SCHEDULE
DEPT
OPERATIONS AND INSTRUCTIONS
MOVE TO DEPT
THIS TICKET MUST BE PLACED ON MATERIAL UPON COMPLETION OF JOB IN DEPARTMENT
MOVE MATERIAL TO DEPT DESIGNATED IN MOVE COLUMN

ORDER NUMBER J1848-5
ARTICLE NAME PLANFILE UNIT
STANDARDS AND INSTRUCTION CARD
ARTICLE NUMBER #1848
QUANTITY 200
BLUEPRINTS 1848-XA 1830-X 1830-XB
STEEL DETAILS 3
LUMBER REQ N.
STD FOR LOT
SCHEDULE
DEPT
OPERATIONS AND INSTRUCTIONS
MOVE TO DEPT
SEND THIS CARD TO DISPATCH STA.______ UPON COMPLETION OF JOB

ORDER NUMBER J1848-5
ARTICLE NAME PLANFILE UNIT
BOARD TICKET AND INSPECTION RECORD
ARTICLE NUMBER #1848
QUANTITY 200
BLUEPRINTS 1848-XA 1830-X 1830-XB
STEEL DETAILS 3
LUMBER REQ N.
STD FOR LOT
SCHEDULE
DEPT
OPERATIONS AND INSTRUCTIONS
MOVE TO DEPT
THIS JOB IS READY FOR INSPECTION
INSPECTED BY
DATE______ NO OF PCS GOOD______ NO OF PCS REJ.______
WHEN INSPECTED RETURN THIS TICKET TO DISPATCH STATION______
17180 10/2 21 SHEAR 21

FIG. 37. Unit Cards Reproduced in Sets for Each Operation—Board Ticket and Inspection Record, Standards and Instruction Card, and Move Ticket

ORDER NUMBER J1848-5
ARTICLE NAME PLANFILE UNIT
GROUP BONUS RECORD
ORDER NUMBER
ARTICLE NUMBER #1848
QUANTITY 200
BLUEPRINTS 1848-XA 1830-X 1830-XB 3
STD. FOR LOT
OPERATION ROUTING
17180 21 SHEAR 21

	EMPLOYEE'S NAME	CLOCK NO.	DATE	DIRECT LABOR HOURS WORKED ON JOB												TOTAL HOURS	BASE RATE	AMOUNT	TOTAL BONUS	TOTAL PAY ON JOB

TOTAL COST
DATE JOB COMPLETED | TOTAL ACTUAL HRS | STD. HRS. | JOB EFFICIENCY

FIG. 38. Group Bonus Record in Recording Direct Labor Time

reduce clerical labor and writing, and assist in avoiding errors in transcribing, a parts route sheet is prepared in the production planning department for each part to be made on a manufacturing order, under straight-line production methods. The parts route sheets, 8½ x 14¼ in., are filed in the post binders. They show routing by departments, operation sequence, standard time, machine and machining numbers, description of operations, and the tools and specifications. If a special tool is required its number is given. Operation sequences are numbered 10, 20, 30, etc., leaving gaps between these numbers so that if an operation is

BILL OF MATERIALS MASTER

NO. OF SHEETS	SHEET NO	WRITTEN BY	DATE	ASSEMBLY NO.	REGISTER NO		REGISTER NO.
1	1	LJH-JLO	4-1-	YHHA-9004A-1			371

ASSEMBLY: CYLINDER BLOCK-STARBOARD ENGINE 4 CYL. V.D.H.A.

	Form	Superimposed variable
DATE OF ORDER		2/6/-
QUANTITY		25
ASSEMBLY NO	YHHA 9004A-1	YHHA 9004A-1
TICKET NOS FROM	1	1
TICKET NOS TO	5	5

PART NO	DESCRIPTIVE NAME OF PART		QUAN	NUMBER	QUAN	NUMBER
H-3003B-1	CYLINDER BLOCK	U	1	1	25	25
H-3079	CAMSHAFT BEARING CAP	U	1	2	25	50
H-3083	CAMSHAFT BEARING CAP	U	1	3	25	75
H-3080B-	CAMSHAFT BEARING CAP	U	1	4	25	100
H-3082B	CAMSHAFT BEARING CAP	U	1	5	25	125

FIG. 39. Assembly Order Master Form for Duplication Showing Superimposed Variable to Right

added between any two operations, it can be numbered between them and thus keep the numerical sequence.

An operation work card (Fig. 42) is prepared by typewriter for each operation on a parts route sheet. In addition to the information on the route sheet the entries include an operation analysis and tentative speeds and feeds of work.

An Addressograph parts plate is made up, showing the part number, the standing order number with a dash suffix to indicate lots, the part name, contract or purchase order number, description or source of the raw material, routing by departments, and total number of operations.

An operation plate, or plates, is embossed showing the part number, a code indicating the number of plates in the series, and the standing order number with the dash suffix. Departmental routings and operation numbers are arranged in columns. Later, the time study is made and data from the study are embossed on the plate.

PRODUCTION OFFICE

1 1 LJH-JLO 4-1- YHHA-9004A-1 371

2/8/

CYLINDER BLOCK-
STARBOARD ENGINE
4 CYL.
V.D.H.A.

25

YHHA
9004A-1

1 5

H-3003B-1	CYLINDER BLOCK	U	25	25
H-3079	CAMSHAFT BEARING CAP	U	25	50
H-3083	CAMSHAFT BEARING CAP	U	25	75
H-3080B-	CAMSHAFT BEARING CAP	U	25	100

SCHEDULING DEPT.

1 1 LJH-JLO 4-1- YHHA-9004A-1 371

2/8/

CYLINDER BLOCK-
STARBOARD ENGINE
4 CYL.
V.D.H.A.

25

YHHA
9004A-1

1 5

H-3003B-1	CYLINDER BLOCK	U	25	25
H-3079	CAMSHAFT BEARING CAP	U	25	50
H-3083	CAMSHAFT BEARING CAP	U	25	75
H-3080B-	CAMSHAFT BEARING CAP	U	25	100
H-3082B	CAMSHAFT BEARING CAP	U	25	125

FIG. 40. Production Office and Scheduling Department Copies Made from Assembly Order Master Form

Parts plates are filed in the planning department by part number, with the corresponding operation plates following them. The operation work cards are sent to the operating departments where they are put in glassine envelopes and filed by part number for use when the job comes into the department.

UNIT REQUISITION

No. of Sheets	Sheet No.	Written by	Date	Assembly No.	Register No.
1	1	LJH-JLO	4-1-	YHHA-9004A-1	371

Assembly: CYLINDER BLOCK-STARBOARD ENGINE 4 CYL. V.D.H.A.

	Unit Cost	Total Cost
MAT.		
LAB.		
BUR.		
Debit / Credit		Total

Date of Order: 2/8/–
Quantity: 25
Assembly No.: YHHA 9004A-1
Ticket Nos.: From 1 To 5

Part No.	Descriptive Name of Part		Quan.	Number
H-3003B-1	CYLINDER BLOCK	U	25	25
H-3079	CAMSHAFT BEARING CAP	U	25	50
H-3083	CAMSHAFT BEARING CAP	U	25	75
H-3080B-	CAMSHAFT BEARING CAP	U	25	100
H-3082B	CAMSHAFT BEARING CAP	U	25	125

Large copy reproduced from assembly order master form in full

UNIT REQUISITION

No. of Sheets	Sheet No.	Written by	Date	Assembly No.	Register No.
1	1	LJH-JLO	4-1-	YHHA-9004A-1	371

Assembly: CYLINDER BLOCK-STARBOARD ENGINE 4 CYL. V.D.H.A.

	Unit Cost	Total Cost
MAT.		
LAB.		
BUR.		
Debit / Credit		Total

Date of Order: 2/8/–
Quantity: 25
Assembly No.: YHHA 9004A-1
Ticket Nos.: From 1 To 5

Part No.	Descriptive Name of Part	Quan.	Number
H-3003B-1	CYLINDER BLOCK	25	25

Individual small copies reproduced for the release of each item on the complete list above

FIG. 41. Unit Requisitions for Release of Parts

From the master parts plate the following forms are made up:

1. Production traveler order.
2. Purchase requisition.
3. Productive material requisition.
4. Productive labor tickets, three for each operation, to allow sending the work through in lots.
5. Move tickets, three to a set, one set for each department shown on the routing.
6. Identification tags, one for each operation, up to a maximum of 12.
7. Job tags, four for each order.
8. Stock tracing record.
9. Balance-of-stores record (on a new part).
10. Two-part production report form, used only in drilling, milling, and grinding departments.

The production traveler order, on a 5 x 8-in. card, is set up to initiate manufacturing, the one shown in Fig. 43 covering the making of a part to go into stores. On this card the scheduled dates of the successive operations are entered, together with the department in which each operation is done. This card then is used as the production record for

OPERATION WORK CARD

RECHECK d1

	DATE	RATE DEPT	FOREMAN
1ST YEAR	3-8-	R.N.	
2ND YEAR	7-11-	R.D.	
3RD YEAR			

No. REQD	TOOLS & GAUGES	A	R	S	BIN
1	3/4" drill gr. 90°				
1	1/4" drill gr. 82°				
1	7/16" drill				
1	gauge - tool marking C-57687				
1	steel block				

DEPT 127 1-27- 190-1100

OPER. 1

Co'sink .532" hole 90° to 19/32" dia. and co'sink burrs from all other holes on both sides.

PIECE RATE 1.52-C
SET UP .32
TEAR DOWN .10

Gauge (1) of (15) pieces.

CLASS .365 STD HRS /C 1.767

HELPFUL REMARKS AND INFORMATION

MACHINE 4 spindle Allen Drill Press

MACHINE NOS. 57-58

NO	Support Selector — C.R.S. OPERATION ANALYSIS	TENTATIVE SPEEDS	TENTATIVE FEEDS
	PICK UP:		
1	190-1100 from machine and position on table at spindle.		
	Co'sink (1) .531" hole 90° to 19/32" dia.		
		ACTUAL SPEEDS	ACTUAL FEEDS
	Pick up piece, hold in both hands and co'sink burr from		
	(1) .531" hole on other side.	410 RPM	
	Co'sink burrs from (2) .2515", (2) .201", (1) .281",		
	(1) .143", (3) .254", and (2) .194" holes both sides.	410 RPM	
	Place piece aside on machine.		
	Gauge (1) of (15) pieces.		
	Handle pieces to machine and finished pieces to truck.		

FIG. 42. Operation Work Card (made out for each operation) (*face and reverse*)

JAN | FEB | MAR | APRIL | MAY | JUNE | JULY | AUG | SEPT | OCT | NOV | DEC | JAN | FEB | MAR | APRIL

PRODUCTION TRAVELER ORDER

190-1100 99999-23456
SUPPORT SELECTOR

1/8" X 5-5/8" C.R.S.
65 FT. 155 LBS. PER 100 PCS.
D-1M-7D-40
4 OPER.

SHOP ORDER DATE JAN. 25 19-

QUANTITY THIS ORDER 1000

COST DATA	
ACTUAL PIECES	
MATERIAL	
LABOR	
BURDEN	
TOTAL COST PER 100 PIECES	

FINISHED		SCHED. DATE		OPER NO	DEPT NO	MACH NO	OPERATOR CLOCK NO	QUANTITY GOOD PCS	QUAN SCRAP	INSP INITIALS	DATE	QUAN SENT AHEAD	DATE	QUAN SENT AHEAD	DATE	QUAN SENT AHEAD
DATE	TIME	MONTH	DAY													
		1	31	mat.												
		2	1	4	1M											
			11	2	7D											
			16	1	7D											
			22	3	7D											
		2	25		40											

3 MONTH'S USAGE

FIG. 43. Production Traveler Order to Initiate Manufacturing of a Part

each operation, showing by what machine and operator the work was done, the number of good and scrapped pieces, and inspector's initials. The quantities sent along, day by day or lot by lot, are also entered for each operation. The finishing time of the last lot on each operation is likewise recorded. This record is continued on the back of the card. In the upper right-hand corner on the front a cost record is provided. The routing by departments and the operation sequence are copied from the master route sheet manually, and the schedule dates for completion of the respective operations are entered from a master schedule book.

CR. INV ACCT NO.

PRODUCTION MATERIAL REQUISITION

PART NO. 190-1100 99999-23456
SUPPORT SELECTOR

MATERIAL 1/8" X 5-5/8" C.R.S.
65 FT. 155 LBS. PER 100 PCS.
SPECIFICATIONS D-1M-7D-40
DELIVER 4 OPER.

SHOP ORDER NO

DATE ISSUED JAN. 25 19-

QUANTITY THIS ORDER 1000

CR. INV ACCT NO

ISSUED	UNIT COST	TOTAL COST
FT (1)		
LBS. (2)		
PCS (3)		

DATE FILLED

ISSUED BY

FILLED BY

FIG. 44. Production Material Requisition for Withdrawing Material from Stores

PRODUCTIVE LABOR TICKET

CLOCK NO | NAME | SHOP ORDER

GOOD PCS | SCRAP PCS

190-1100 99999-23456
1M 4
7D 2 .69 .12 4.07 4.52
7D 1 .32 .10 1.52 1.767
7D 3 .11 4.55 5.05

IBM 726742 MG

OK'D BY | OT HRS. @ = + ½ = | TIME HRS @ =

TOTAL GOOD PCS | TOTAL SCRAP PCS. | X WAGES P W LOSS | BURDEN

ELAPSED TIME | TOTAL PCS FIN | JOB WAGES | SET UP & O T

OPERATION NO

STATUS OF JOB

Fig. 45. Productive Labor Ticket for Recording Time, Wage Rate, and Earnings on Jobs

The schedule dates in the master schedule book are arbitrarily established in accordance with the total number of operations on a piece part. The final due date (always set on a Friday) is entered on the production traveler order first. By referring to the schedule book table, the clerk works back from the final operation to the first operation, entering the schedule date opposite each operation, in turn.

A purchase requisition form, filled out by Addressograph plate, is made out when material is to be obtained from outside. Material is withdrawn from stores by a punched card (Fig. 44) which provides spaces for the amount issued, date of issue, unit cost, and total cost.

FN-570-61 100m sets 5- **MOVE TICKET**
THIS COPY FOR PROD. OFFICE

216-1132 SHAFT 3416-23456

1-1/4"DIA.C.D.SAE-X-1315
300 FT. PER 100 PCS. 1250 LBS.
D-2-8-2-8-2-10-40
16 OPER.

Date **Due Date**

Amt. Del.

Received By

Delivered By

Fig. 46. Move Ticket Prepared in Triplicate

Productive labor tickets (Fig. 45) are run off for each operation, the plates carrying data on rates on various operations per 100 pieces, department number, operation number, set-up time, tear-down time, and standard hours per 100 pieces. These tickets carry spaces for entering starting and finishing times, good and scrapped pieces, elapsed times, job wages, burden, and whether the employee is working on piecework or daywork. On the back are spaces for entering machine number, due date, employee's number, and quantity. These productive labor tickets are issued from the master operations plate based on total number of operations on the piece part. An arbitrary factor of three is used so that

FIG. 47. Identification Tag for Routing Order

a six-operation plate will have eighteen labor tickets issued from it. The standards data do not appear on the labor tickets for the initial lot. Rates as established by time study must be entered on these tickets manually by the time study man in the shop and the time study sheets provide the information for embossing this data on the plate so that subsequent labor tickets will carry that data. Inspection and scrap tickets are used to account for good pieces and spoilage.

The work is moved between operations by carbon-backed move tickets (Fig. 46) prepared in sets from plates, the sets consisting of a copy for the production office, one for the department receiving the work, and one for the department delivering the work. From these move tickets entries are made on the production traveler order as to the progress of the job. An identification tag (Fig. 47) goes with and routes the order.

On one side this tag shows operation numbers from 1 up to 56, with a column in which to enter the machine number on which each operation is done. On the reverse of the tag is the plated identification entry.

These identification tags are issued in quantities corresponding to the total number of operations on the piece part up to a total of twelve operations. For more than twelve operations, only twelve tags are issued. The operator uses the identification tag for job identification when he communicates with the timekeeper to ring in or out on a job. The date is stamped on when the order is actually released and the raw material is moved from raw stores to the first operating department. The final due date for the last operation on the piece part is manually entered at the bottom corner of the tag. This date is entered by the clerk at the time posting is made to the traveler order and the progress record.

A job tag, four of which are prepared for each order, is also used to keep lots from getting mixed. It carries an Addressograph notation of

STOCK TRACING RECORD

190-1100 99999-23456
SUPPORT SELECTOR
1/8" X 5-5/8" C.R.S.
65 FT. 155 LBS. PER 100 PCS.
D-1M-7D-40
4 OPER.

DATE MATERIAL RELEASED JAN. 25 19–
QUANTITY THIS ORDER 1000
DATE DUE IN STOCK 2/25

OPER.	4	2	1	3														
DEPT.	1M	7D	7D	7D		40												
OPER																		
DEPT.																		
OPER.																		
DEPT																		

OPER NO	DEPT	SHIFT			DATE	CLOCK NO	MACHINE NO	QUAN PROD	SCR	ACCUM NET PROD	OPER NO	DEPT	SHIFT			DATE	CLOCK NO	MACHINE NO	QUAN PROD	SCR.	ACCUM. NET PROD
		1	2	3									1	2	3						

Fig. 48. Stock Tracing Record for Expediting the Work

the part, the final due date, and the number of containers and the kind used.

A stock tracing record (8½ x 11 in.), shown in Fig. 48, is prepared to expedite the work. It carries the data describing the item and the materials, quantity on the order, date material is released, date the item is due in stock, and spaces for entering the sequence of operations, with the departments in which these operations are to be performed, and a record of production by shifts to assemble information on quantities passing inspection, amounts scrapped, and accumulated net production.

The above forms are placed in a 7½ x 10½-in. brown envelope on which the part identification has been entered by Addressograph plate.

On a new part, a balance-of-stores record (5 x 8-in., Fig. 49) is prepared from the parts plate. This card has space alongside the parts plate impression in which are entered manually information pertaining to manufacturing quantities, a space "See Stores Record" in which is inserted the maximum size of a lot in cases where there are definite limi-

tations in handling capacity due to bulkiness or size of parts, either in the fabricating departments or in the stockroom, the reorder point, three months usage, time required to get material and fabricate, and reorder time which represents time required for issuance of an order plus time for securing material, plus time for fabricating, plus time for inspection, plus a "cushion." The material time box is used only in those cases where there is something exceptional concerning the time required for getting raw material. On this form are entered the date, order number, due date and quantity, and space is provided to show the date and quantity received as well as the information pertaining to quantities issued and balances. At the bottom are entered the monthly and yearly usage, the assemblies and models on which the part is used, and the part number.

A two-part production report form is used in certain operating departments only, namely, grinding, milling, and drilling. Where these depart-

190-1100 99999-23456
SUPPORT SELECTOR
·1/8" X 5-5/8" C.R.S.
65 FT. 155 LBS. PER 100 PCS.
D-1M-7D-40
4 OPER.

MFG. QUAN | LOT QUANT
SEE STORES RECORD | FABR & MATL TIME WORK DAYS
RE ORDER QUANT | RE-ORDER TIME WORK DAYS
3 MONTHS USAGE DATE QUANT | MATL TIME

ORDERED				RECEIVED		ISSUED			
DATE	ORDER	DUE DATE	QUANT	DATE	QUANT	DATE	ORDER	QUANT	BALANCE

ISSUED			
DATE	ORDER	QUANT	BALANCE

SHORT LIST QUANTITY | DATE LISTED

JAN	APR	JULY	OCT
FEB	MAY	AUG	NOV
MAR	JUNE	SEPT	DEC
PART NO		YEARLY USAGE	

QUAN | ASSEM & MODELS | M | L | B | T

FIG. 49. Stores Record for Entry of Orders, Receipts, Issues, and Cost Data

ments appear on the routing, four production report forms are issued for each operation performed in those departments. This form is filled out by the time clerk when an operation is finished. The pink copy is given to the operator who uses it to check the amount of pay received at the end of the pay period. The original copy is sent to the progress record section of the material control department and used to post that record for operation moves. (The original copy of the move ticket is also sent to materials control for posting to the progress record when a job moves from one department to another.)

TELETYPE.—The teletype is a typewriter electrically operated over a regular telephone circuit. It will simultaneously type orders and instructions at several widely separated points. A centralized production control department can therefore issue orders to different plants, or can modify schedules at all plants at the one time. These plants in turn can report back information on production, inventories, machine or equipment loads, orders to be put through, and other data regarding the manufacturing situation. By the same means, manufacturing orders,

written from customers' orders for the company's products, can be sent over the wire and typed at the plant which may fill such orders. It is the practice of some companies to have a certain time and period each day for which they engage and pay for this service.

TELAUTOGRAPH.—Another device for transmitting instructions is the telautograph, which is used to write at local stations messages which are written at a sending station. It is effective in production control work for communicating orders and instructions to operating departments. In dispatching, particularly, it is especially useful. For example, on assembly lines where important subassemblies of varying kinds must be brought together for other subassembly work or final assembly, it is necessary to synchronize the completion of the respective units. The telautograph, which writes a record of messages sent, will record the information as to progress on units due for completion so that the departments needing these units will know in advance whether they are coming through on time, and, if there is to be any delay, or any change in the preestablished sequence, can change their plans accordingly without causing any jam of work. The automotive industry has made use of devices of this kind to synchronize delivery of body to chassis on the final assembly line.

TEMPORATOR.—The temporator is a dialing device operating by an electro-mechanical method. Usually the control board is located in the production control department and visible and audible annunciators are located in the various departments of the plant. The system has two-way communication. The dials used by the workers to communicate, usually by code, with the central office register letters and digits there and also at the local sending station.

Over the system from the central board go instructions to the local stations covering the methods and times of doing work, especially in case of changes, and requests for information on the status of certain jobs. In general, either the local dispatcher or the workers report on the completion of individual jobs, communicate delays, breakdowns of equipment, failures of material to arrive at work stations, and other interruptions or violations of plans and schedules. Reports on completed jobs cover job numbers, station or machine numbers, operations started or finished, workers' clock numbers or names, quantities produced and amount of spoilage, time taken on jobs, and all similar kinds of data. The facts and figures are dialed by means of letter symbols and numbers to the central station where production boards, charts, visible index systems, punched-card systems, or other production control systems are kept, so that as soon as any work is finished the central production control office may have the information and bring its records at once up to date.

PNEUMATIC TUBE SYSTEMS.—Growing use is made of pneumatic tube systems for conveying information and articles to and from central stations and local departments in larger manufacturing plants. Where a plant has scattered buildings, multistory buildings of several floors, or the modern long and wide single-story buildings running up to 2,000 or more feet in length and 500 or more feet in width, the time lost and the high expense involved in messenger service is quickly

repaid, and much prompter and speedier production results, through the use of pneumatic delivery.

Drawings, drawing lists, bills of material, specifications, change orders, samples, etc., are sent between the engineering department and the production control department directly, promptly, and safely in regular course, or upon telephone request, thus advancing the work of planning orders, or making changes in those under processing.

The central production control office has direct connection with its local stations from which operations in the various departments are directed and regulated. Work orders, blueprints, instruction cards, inspection and move orders, time tickets, material issue slips, tool list and tool issue slips, instructions for scheduling, change orders, and all other papers and forms needed are sent out to local dispatchers over such a system. Reports on the status of jobs, delay reports, and all the returns made when jobs are finished—instruction cards, blueprints, output reports, inspection reports, time summaries, etc.—go from local stations to the central office for immediate posting. The local dispatch stations may have similar communication with storerooms, for transmitting material issue slips, tool cribs for sending tool issue slips and lists, including workers' checks or withdrawal slips, the payroll department to which workers' time tickets are sent, the cost department for data on jobs, and perhaps the toolmaking department.

Not only papers and drawings are handled by pneumatic systems. Small samples, small tools or devices going to and from tool cribs or toolrooms for use, return, change, or repair, small parts from storerooms, small replacement items to take care of shortages or spoiled work, and other objects. Carriers come in various sizes for the different uses, typical of which are (Lamson):

- 2¼ in. diam. for time and job tickets, requisitions, light tools, etc.
- 3 in. diam. x 9 or 10 in. long for average service.
- 4 in. diam. x 10 in. long, also in 12 and 14 in. regular length and up to 42 in. in special lengths, for quantities of papers and small tools, gages, samples, etc.
- 4 in. diam. x 8½ in. long for punched cards, small parts, tools, and may be lined to carry bottle samples, etc.
- 4 x 7 in. oval (for oval tubes) x 14 in. long for small articles, samples, booklets, files of papers, etc., also available in 16 in. length.
- 3 x 12 in. (rectangular) x 15 in. long, for letter file of papers without folding, larger samples, tools, etc., and in 28 in. length for blueprints and drawings.

A movable indicating ring is set to a fixed indicator ring on the body of the carrier, containing the station numbers in the system, thus enabling the sender to show where the carrier is to go.

Typical of the use and economy of such systems in production control are the following cases. In the Douglas Aircraft Co., 3 x 12-in. Lamson tubes for blueprints not only continually saved time but also reduced the number of blueprints needed by at least 40%. Previously, blueprints were sent to at least five key departments, and occasionally to as many as 15. Under the tube method of distribution, only two blueprints are necessary in each case—one on call and one in reserve. The department needing a print receives it and then returns it when the work is done, so that the same print can be used by a succession of

departments, the reserve copy being available when two departments need the print at one time. This company also uses tubes to handle orders, requisitions, etc., throughout its many departments. A steel company reported savings of $4,200 per year from a control installation. In the Consolidated Aircraft Co., a tube system linking seven buildings saved $150,000 annually in messenger service alone.

A large plant with (1) a central office building in which were the central plant mailing department and the factory office dispatch station, (2) a machine-shop building, and (3) a combined steel-shop and assembly building in which was a steel shop and shipping department office, connected all three of these stations—mailing, factory office dispatch,

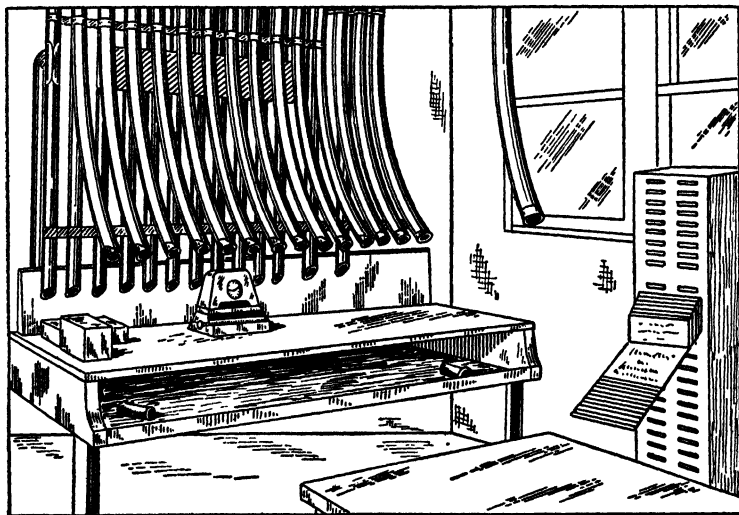



FIG. 50. Dispatch Station of a Pneumatic Tube System At Which Scheduling and Control Enter

and steel shop and shipping office—by a 3-in. pneumatic tube trunk line. From these stations there radiated, in addition, the following lines:

Mailing department: 3-in. tubes to factory office, cost, stock, payroll, sales, purchasing, production planning, receiving, and experimental.

Factory office dispatch station: 3-in. tubes to mailing, pattern shop, and first aid; 2¼-in. tubes to grinding, polishing, drill press, milling machines and lathes, special machining and sheet metal, screw machine, punch press, cable and wire line assembly, leather working and pneumatic assembly, cleaning and carburizing, spraying, and toolroom.

Steel shop and shipping office: 2¼-in. tube to template room, fabricating department, gravity assembly, steel work assembly, paint shop, and boxing and shipping.

The above system was installed to facilitate production planning and control and factory cost control. It distributes factory orders, stock orders, time tickets, job tickets, purchase orders, and mail.

Fig. 50 shows the tube system, production record files, and work control center in the factory office central dispatch station.

ELAPSED TIME RECORDERS.—It is customary in many plants to use an electric clock to stamp time tickets given to workers when they start jobs, and to stamp the tickets again when the workers turn them in after the jobs are finished. This practice is quite regularly followed where employees are on piece rate or other incentive systems under which there are standard times set for jobs, so that the time factor influences the rate of earnings. The clocks used may stamp hours and minutes, but where jobs are of not too short duration, and to facilitate calculations, many clocks installed register only in tenths of an hour, that is, they change only every 6 minutes. Subtractions to find elapsed time, therefore, are expressed in hours and tenths, making earnings calculations easy. In fact, tables are often used to simplify the work further. Certain types of recorders automatically determine and stamp the elapsed time. To prevent errors, it is usual to synchronize all time clocks and elapsed time recorders so that all read alike throughout the plant.

CALCULATING MACHINES.—These machines are used in connection with many production control systems. Since they form part of the office equipment in a large percentage of companies, no explanation of their nature and use is necessary here.

TELEVISION.—There are indications of a wider industrial use of television to project, in colors, forms, sketches, drawings, parts, subassemblies, and so on, and that it will be adapted to production control so as to reduce the time required for personal contacts, speed up control and factory operations, reduce mistakes to a minimum, and speed up communication.

SECTION 4

PURCHASING

CONTENTS

Purchase Contracts

Purchasing Procedure

Purchasing Department Records

Purchase Record Systems

Reports to Management

SECTION 4

PURCHASING

DEFINITION.—In industry, purchasing is the procuring of materials, supplies, machines, tools, and services required for the equipment, maintenance, and operation of a plant.

The purchasing department is the department intrusted with this procurement duty. The function of the purchasing department is to procure needed materials, supplies, machines, tools, and services, at an ultimate cost consistent with economic conditions surrounding the item being purchased and safeguarding the standard of quality and continuity of service, and to establish and maintain the company's reputation for fairness and integrity. Modern trends in legislation make it essential that the purchasing department also should watch carefully the enactment of new laws as to taxes, business regulation, etc., and insure the company against their violation.

Procurement of goods through purchase accounts for about half the money spent by the average industrial concern, the range among different industries being from about 20% to 90%. The financial aspect of purchasing, therefore, is obviously of great importance. Only by close and intelligent cooperation between financial and purchasing functions can proper financial control be effected.

MAJOR IMPORTANCE OF PURCHASING.—Purchasing is of major importance because:

1. It is a primary function. Proper sales cannot be made unless materials being used in manufacture, or for resale, are bought at an ultimate cost commensurate with that to competitors.
2. Efficient operation of any industry depends upon proper turnover of investment. The purchasing department must arrange its purchases so as to insure receipt of proper materials when wanted in sufficient quantities to maintain production and on-time shipment; at the same time it must not increase investment beyond that required to meet current needs and maintain a reasonable factor of safety.
3. By its close contacts with many other companies and the general market, the purchasing department is in a position to advise its company on:
   a. New materials which may be used to advantage as substitutes for materials in use.
   b. Possible new lines of products to be added.
   c. Changes in trends, either in prices or other factors, that will affect the sales of the company.
   d. Building up goodwill in the business world with which it deals.

   Its contacts with vendors, market trends, and manufacturing and marketing policies in the industries make it possible for this department to contribute invaluable help in framing plans, whether for

initiation of new products, scheduling of production, determination of marketing policies, or some other branch of industrial operation.

DUTIES OF THE PURCHASING DEPARTMENT.—The duties of the purchasing department cover all dealings with vendors. No contacts looking to the purchase of any goods or services should be made without cognizance of this department. Only with the consent of, and preferably in the presence of, some member of the purchasing department should other departments receive or confer with vendors' representatives.

Its principal duties, not necessarily listed in order of importance, are:

1. Locating and selecting sources of supply for materials or services required.
2. Knowing in considerable detail the operations and processes carried on in the plant, the materials requirements of these operations, and the general plan and procedures in production control and materials control.
3. Procuring materials and service as required.
4. Placing shipping orders against purchase agreements.
5. Following up suppliers to make sure that shipments have been made.
6. Making sure that the quantity and quality of materials ordered are secured.
7. Approving bills for payment.
8. Securing adjustment on claims for shortage, poor quality, etc., in material received on purchase orders.
9. Maintaining records necessary for proper operation of its function.
10. Knowing the factors governing cost of production—demand, supply and cost of materials, and labor needed in production.
11. Knowing business law as it governs contracts and sales.
12. Assembling and analyzing data on markets, commodity supply and demand, price trends, etc.
13. Keeping in touch with general business trends.

FUNCTIONAL ORGANIZATION OF PURCHASING.—Fig. 1 shows a functional organization chart covering most of the duties which may be assigned to a purchasing department. For a large plant engaged in an extensive line of manufacturing, say, in the metal-working field, the chart may constitute the general set-up of the purchasing organization, in which an assistant purchasing agent heads the buying section, broken down into small units under buyers, much along the lines suggested by the chart. In line with recent developments a subcontracting section may be added, and a section to handle all contracts let outside for plant construction work of any kind.

The various functional sections, in the case of smaller plants, may be combined in groups under fewer heads, according to each plant's own requirements, or assigned elsewhere in the company organization. But all of these functions must be provided for in some way in any company —even though only in a rudimentary way—as the following comment indicates:

1. **Buying Section.** At least one person must do the buying. In a large company the function is subdivided more and more according to specialized lines.
2. **Follow-Up Section.** Separate in large companies. Buyer does or directs the work in small companies.

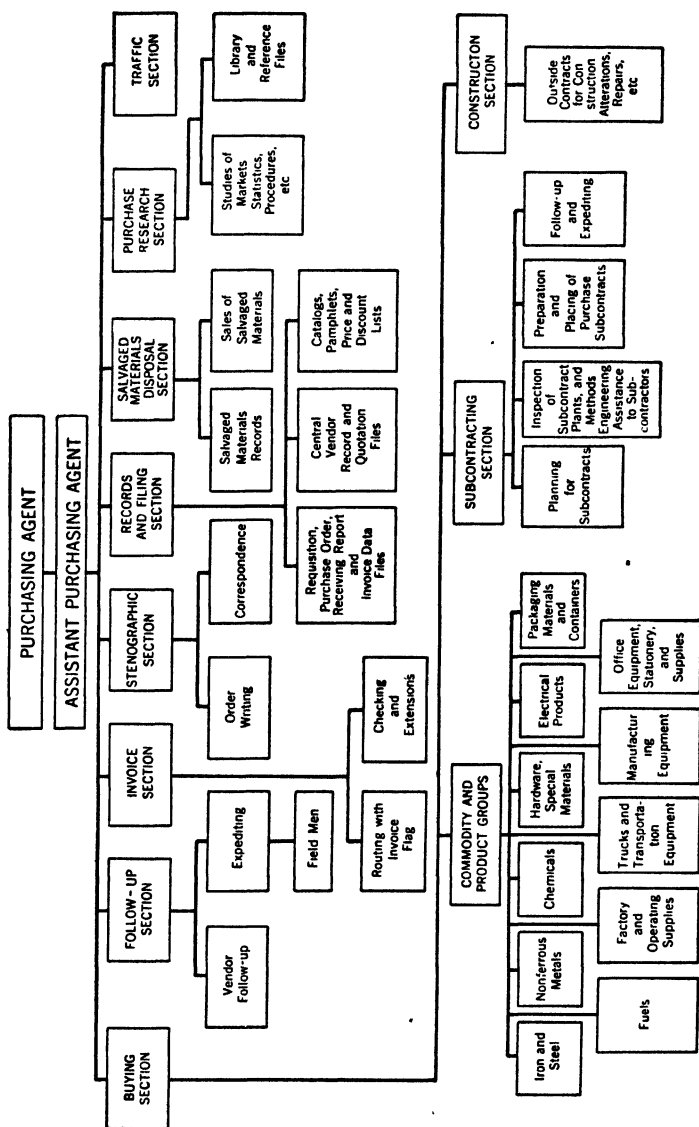



Fig. 1. Functional Organization Chart of a Purchasing Department

3. **Invoice Section.** Invoices checked by invoice clerks in large companies, by buyer or purchasing agent in a small company. Sometimes, however, this work is done in the accounting department.
4. **Stenographic Section.** Separate in large companies where work can be pooled to cut down number of stenographers. Buyers sometimes prefer to have full time of definite stenographers. One stenographer in a small company will probably do follow-up, invoice checking, stenographic work, and filing.
5. **Records and Filing Section.** Sometimes separate in large companies, for efficiency. Often, however, buyers have their own files which are maintained by a stenographer or clerk. In a small company, the stenographer will do this work.
6. **Salvaged Materials Disposal Section.** Records and sales of salvaged materials are under direction of the purchasing department in many large organizations. Sometimes all salvage work, from collecting to reconditioning or sale, is handled by a separate department. In a small company, the shop or the purchasing agent may sell the items.
7. **Purchase Research Section.** Organized only in large companies, and not always in them.
8. **Traffic Section.** Under purchasing in cases where incoming shipments are a larger and more complicated responsibility than outgoing shipments. Often under sales when the latter involve more responsibility. In large companies, usually set up as an entirely separate department.

Purchase Organization

CENTRALIZATION OF PURCHASING.—The first question to be answered as to the organization of a purchasing department is: How far should purchasing be centralized under one head? If the company operates only one plant, then a central purchasing department, or at least one person in charge of all purchasing, is the best plan to adopt. If the company has more than one plant, then many factors must be considered to find out to what extent to centralize: degree of geographical separation of plants; essential homogeneity of products manufactured; type of materials forming bulk of purchases; whether items are bought in large volume and are peculiarly susceptible to market changes; location of suppliers, and other questions.

An **axiom of purchasing** is that the function should be under a single head, whenever it can be centralized without substantial sacrifice in efficiency due to restriction of local initiative. The advantages of undivided responsibility, maintenance of consistent buying policies, and largest possible buying-power as a means of exerting buying influence, are great. With centralized purchasing all records with regard to purchases are in one place and under one supervision. This works economy both in compilation and consultation of records, and permits quick and effective advantage to be taken of changing market conditions. It also points the way to standardization of specifications and elimination of slight differences in the material called for, which may be costly. It tends toward reduction of inventories that must be carried and consequent investment of money. Moreover, centralized purchasing means

lower selling costs to vendor, since there is only one purchasing agent to be solicited instead of a number. Lower selling cost inevitably means eventually lower buying prices. Centralized purchasing should be the rule for any concern operating a single plant. Also, when there are two or more plants in the same section of the country, with a fairly homogeneous product demanding the same general types of material, centralized purchasing will give the best results.

LARGELY LOCALIZED PURCHASING.—At the other extreme is the concern operating several plants in widely separated locations, and manufacturing different products, so that each has individual material requirements quite different from those of any other. Here considerable localized purchasing may be preferable, that is, a separate purchasing department and a purchasing agent for each plant, the purchasing agents to be part of the local plant organization and to serve mainly the needs of their own respective plants, but to be supervised by a general purchasing agent who establishes and enforces the general purchasing policies, and sees that the mechanics of purchasing are enforced at each plant and that there is proper interchange of ideas and information. The general purchasing agent will execute most of the contracts to be drawn upon by more than one plant, and will check or audit the work of the local purchasing agents, who will usually submit periodic reports to him.

CENTRALIZED-LOCALIZED PURCHASING.—Between these two extremes are many companies operating several plants whose geographical locations may not be too widely scattered, and whose product and material requirements, while to a considerable degree heterogeneous, may nevertheless cover purchases of a large number of similar parts and materials used in common and in large quantities. Under such conditions it is desirable partially to centralize and partially to localize the

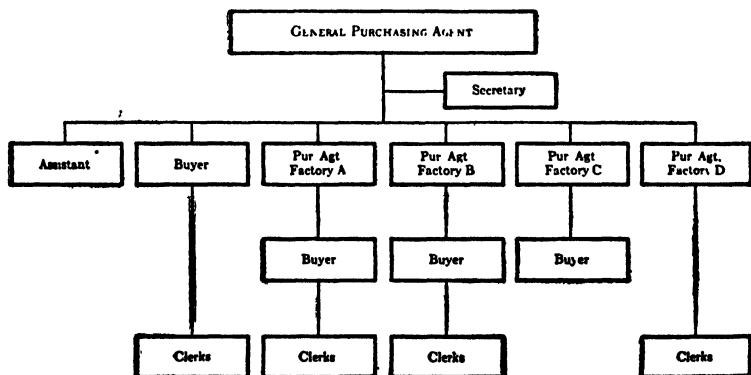



FIG. 2. Purchasing Organization in a Company with Combined Central and Local Buying (Manufacturer of chemicals with 15 scattered plants. Annual purchases over $25,000,000)
(Handbook of Purchasing Policies and Procedures, vol. 1, N.A.P.A.)

purchasing function. A general purchasing department should be set up to establish general policies, to do actual buying when advisable, and to supervise and direct the work of local purchasing departments which will be set up at each plant.

Where a large degree of **localized purchasing** is practiced, consideration must be given to items used by all plants, on which preferential discounts for quantity contracts are available, but which can be obtained only by contracting for the requirements of all plants and specifying delivery to individual plants against the contract. Such situations are covered by a form of pooled buying. The individual plant which is the largest user of the material, especially if in the locality where this material comes from, buys for all plants on the basis of estimates, although such contracts may actually be written and put through by the central purchasing organization. Goods are shipped to each plant as specified and charged to the plant receiving them. Here again there must be coordination through a central purchasing department because the plant using the major portion of the requirements may not be in the best position to buy the total amount needed.

A typical set-up of a partially centralized, partially localized purchasing department is shown in Fig. 2.

Conditions to Govern Centralized-Localized Buying.—The requirements for the successful operation of such a plan are:

1. The general purchasing agent will establish policies, procedures, basic forms, record-keeping methods, and other fundamentals necessary for uniformity throughout purchasing and adequate central control, and will delimit the authority and the range of buying of each local purchasing agent.
2. All local transactions will be reported at once to the central office, duplicates of contracts, and perhaps periodic summary reports of activities, being sent there.
3. Local commitments must remain within the purchase budgets of the respective plants as to the amounts for each material, and the total monthly expenditures.
4. A limit may be placed upon the amount which the respective local purchasing agents may expend upon any one purchase order.
5. Special purchases, excessive-quantity purchases, and any other deviation from the range of authority given to the local purchasing agents must have the approval of the central office.
6. The local situation as to requirements, stocks, etc., and data on local vendors, markets, prices, etc., for important material and supplies bought locally will be reported by each branch purchasing agent to the central headquarters.
7. Local purchasing agents will draw orders to ship against contracts placed by the central purchasing department covering the needs of two or more plants.
8. The plan should be kept flexible. Different local buying authority or assignments may be given at different times, as markets or conditions shift or change.

Some of the different types of contracts negotiated under such a plan of organization are:

1. Contracts made by headquarters, copies sent to branches. Orders placed directly by branches on supplier, duplicates being sent to central headquarters; all service questions handled directly by branch with supplier; bill sent by supplier to branch and paid by branch.

2. Contracts made by headquarters, copies sent to branches. All orders sent to headquarters for placing; all service questions handled through headquarters; bills rendered to and paid for by headquarters, which rebills to branches.
3. Contracts made by headquarters, copies sent to branches. Orders sent to headquarters for placement; service through headquarters; billing direct from supplier to branch. This class of contract is useful when there are two or more contracts for the same material with different suppliers, making it necessary to place orders consistent with current conditions at suppliers' plants.
4. Contracts made by the local plant, covering the requirements of several or all plants. Orders, service, and bills usually handled between supplier and branches, with copies of orders sent to central headquarters. Even though negotiations are conducted by the local buying plant organization, contracting power should be centralized. Preferably, such contract should be signed by the general purchasing agent. Copies of all contracts should be a part of the record of the general purchasing department.

The tendency in purchasing in a company with one plant is distinctly to set up centralized purchasing, and there is a definite trend away from purely independent localized purchasing in companies having more than one plant.

COMBINATION OF PURCHASING WITH OTHER FUNCTIONS.—There are certain functions of industrial organization which are so closely correlated to purchasing as to lead to the consideration of the question of whether or not they should be included under purchasing, and made an integral part of the purchasing organization. These are: receiving, materials inspection, storeskeeping, and traffic.

Receiving is part of the job of procurement in small organizations. In some small companies, the purchasing department is held responsible also for storeskeeping, investment, and physical handling. Unless reasons of economy make it essential to unite these functions, the better practice is to separate receiving from purchasing, on the theory that the purchasing department which negotiates the buying arrangements should be checked by a separate department which reports the completion of the transaction.

In cases of centralized purchasing for a number of plants, individual receiving departments for each plant under direction of the plant managements are desirable, usually as a part of the manufacturing or the production control department. Even in such cases, the receiving department may report to the general purchasing department, which should conduct all negotiations with vendors about shortages, nonreceipt, etc. In large organizations, the receiving department should be under the general plant management, as above indicated. The reason for this recommendation is found in the line of thought that the physical handling of materials, receiving, inspecting, storing, reissuing to manufacturing departments, handling work in process, and packing and shipping finished goods, are specialized functions requiring specific training and an entirely different type of supervision and help from that necessary for purchasing.

Inspection of incoming materials, rightly considered, is no part of purchasing duty. It should be independent of the purchasing department, although all disputes as to quality, maintenance of specifications, etc., should be referred to the purchasing department for adjustment

with the vendor. In this section inspection is excluded from the purchasing function and organization.

Storeskeeping may or may not be part of purchasing duty, on the same line of reasoning as indicated in the paragraph above on receiving. In a large plant or in a concern operating more than one plant, it should undoubtedly be a separate unit, usually under the manufacturing or the production control department. In a small organization, operating but a single plant, it may sometimes be desirable to unite the two functions. Generally speaking, the trend is toward separation except in very small organizations, in which economy of operation dictates merging of these functions.

Traffic, as has been previously indicated, is not always a purchasing function. Incoming traffic deals with purchased materials in large part; outgoing traffic has no such relation. The general practice is toward separation of traffic and purchasing, except in a very small organization where economy makes consolidation essential.

RELATION OF PURCHASING DEPARTMENT TO OTHER DEPARTMENTS.—Departments in an industrial organization with which the purchasing department must coordinate most closely are: storeskeeping, production, engineering, traffic, accounting, sales and financial.

Stores Department.—The storeskeeping or stores department is in most direct contact with the purchasing department. On all commodities which are carried in stock, the stores department sends requisitions for replenishment to the purchasing department, and the purchasing department purchases on the strength of these requisitions. Upon receipt of goods from the receiving department, the stores department is responsible for their safekeeping and disbursement. Beyond these contacts, the two departments have other interests in common, in which they must cooperate—inventory control and the determination of order quantities. On the one hand, the stores department must keep the purchasing department informed as to rate of use, etc., of each item, in order that the purchasing department may buy efficiently. On the other hand, the purchasing department must have a means of keeping the stores department constantly informed as to economical ordering quantities from a purchasing standpoint, so that the stores department may endeavor to keep inventories at the lowest efficient level.

Hence, every **requisition from stores to purchasing** should contain all such information about stock on hand, rate of use, and known future requirements, as will enable the purchasing department to place its order with the vendor for the most desirable quantity from all points of view and for delivery at proper time. The purchasing department should follow a systematic method of informing the stores department about prospective changes in market conditions or price levels that may make it advisable for stores to anticipate its requirements for a given commodity. The purchasing department has a primary opportunity for initiating information of this kind.

Often the stores department, on the basis of its record, will requisition from the purchasing department a quantity of some material which carries a higher purchase price than would apply to a moderately larger quantity. It is obviously the duty of the purchasing department to increase such a requisition to a quantity economical for purchase. This

step should not be taken, however, without notification to the stores department because:

1. The stores department is primarily responsible for control of inventory and it is unfair to take any steps which will increase inventory without notifying the stores department in such detail as to make the increase satisfactory or to give opportunity to debate its advisability.
2. The stores department is entitled to a knowledge of the quantity it is to receive against its requisition, and will undoubtedly question the receipt of a quantity greater than requisitioned.
3. It is a matter of clerical economy to have the stores department keep records on economical ordering quantities and other data which will enable it to requisition in proper quantities in the future and save further notifications.

A distinction is made between **authorization to purchase,** which is a stores department's agreement to a commitment to take material over some period in the future, and a requisition, which specifically requests a definite quantity at a definite date. An authorization to purchase is a prelude to the execution of a purchase contract covering a future period, whereas a requisition results in a direct purchase order, or in the placing of an order for a partial shipment against a contract already placed.

There is also a clear distinction between **ordering quantities** and **commitments.** The purchasing and stores departments can agree, for example, that all orders for a contracted article put up in standard cases will call for multiples of the standard cases, and that some material will always be ordered in multiples to make up a minimum or a maximum carload. Where a quotation is given f.o.b. supplier's plant (freight allowed on shipments over a certain total weight), the purchasing and stores departments may arrange to place orders exceeding the minimum necessary to get the allowance for freight.

Another condition requiring agreement of the purchasing and stores departments is the **quantity and period to be covered by future commitments** or contracts. It is the purchasing department's responsibility to determine the probable price trends and to estimate the possible savings by making commitments for the period recommended. It is the stores department's function to balance these estimated savings with the possible cost or losses in storing which may be caused by the commitment.

For example, the purchasing department may be able to obtain an exceptionally low price by buying a year's supply, taking immediate delivery, and making cash payment. This apparent saving may be wiped out due to the fact that in order to store it the stores department must rent outside space, have double handling expense and run the risk of a possible change in design which would make the material obsolete before the stock was exhausted. This case also involves the financial department, as a cash payment at that time may seriously affect the bank balances and it may be inadvisable or impossible to borrow to meet the payment. Cases occur, generally involving company relationship as well as price and delivery, where future commitments are sufficiently important to be laid before the board of directors.

Records as to future commitments are ordinarily kept in the purchasing department, and the responsibility for taking out the full amount

of commitments and deciding when new commitments are advisable rests with the purchasing department. The stores department, having assented to the commitment, is obligated to furnish requisitions which will enable the purchasing department to issue the necessary releases against the commitment.

Another point on which agreement is necessary is to distinguish between items that move regularly in large quantities and are dependent upon a **predetermined production schedule** of the production department, and **regularly stored items** on which the use fluctuates. In an automobile assembly plant, for example, parts for bodies come from one plant and bolts and nuts for assembly usually from the plant of an outside vendor. In the first case little or no stocks are carried, daily deliveries being made according to the rate of consumption. In the case of the bolts, a stock is maintained and orders are placed when predetermined order points are reached.

Production Control and Maintenance Departments.—Production control department requisitions are based on determined manufacturing schedules, and quantities, therefore, are not open to increase by the purchasing department action without provision of a use for the surplus above the amount required for the production schedule. The same reasoning applies to requisitions from the maintenance department or any department that requisitions for use for a particular job or purpose and not for stores. It is good practice to route all requisitions not originated by the stores department through that department, so as to eliminate the possibility of duplication, i.e., ordering the same material for stores and for production or maintenance, with the resulting building of unnecessary stocks and failure to make full use of stores. When such requisitions are not so routed, the purchasing department must assume the responsibility for seeing that purchase orders are not sent to vendors for items which are in stores. There will be exceptional cases, of course, in which production or maintenance may require sufficient material for a given project to justify separate requisitions and orders, reserving the stock in stores for regular and minor uses.

The **joint responsibilities** of the production control and purchase departments in planning to buy and in buying are these: Assume that the production control department has complete charge of the needs of the plant, is responsible for inventories, determines the materials or supplies required, and the rate at which they are required. With this assumption the several responsibilities are:

Production Control:

1. To supply information, by item or class of material, regarding the estimated future demand as far in advance as necessary (this period to be determined by joint conference between the purchasing and production control), the condition of stocks, storage facilities, rate of consumption, and any other special factors that are peculiar to the item.
2. Furnish definite authorization for commitments.

Purchasing:

1. When to buy.
2. From whom to buy.
3. How to buy—spot purchase, contract, etc.
4. Price to pay.

Jointly:
1. Order point.
2. Minimum ordering quantities.
3. Ordering multiples.
4. Advance purchases.
5. Stocks to be carried.

Engineering Department.—When the engineering department develops the designs of products, or checks and adapts customers' drawings if the design is prepared outside, the purchasing department is interested in having as many as possible of the specifications set up conform to materials, parts, and products on the market. Cost of items bought will thus be held to reasonable figures. Likewise, it is desirable to have the engineering department standardize on certain materials, parts, etc., so that these may be bought in large quantities to get good discounts, cut down the number of purchase orders placed, and reduce the quantity and variety of items carried in the storeroom. In the designs, also, the purchasing department is concerned with simplicity. Drawings of cast parts, for example, may indicate so many possible complications in casting that the purchasing department may have difficulty in securing acceptable quotations from outside vendors.

The engineering department often prepares bills of materials and these are highly important to the purchasing department as central sources of information on materials and parts, and because their preparation centralizes and speeds up the getting through of purchase requisitions, thereby avoiding pressure to get in rush shipments from vendors when the placing of purchase orders has been delayed.

Traffic and Other Departments.—The relationships of purchasing with traffic arise principally through the routing and tracing of incoming shipments; with sales through the budgets, for the purchase budget is dependent upon the sales estimates; and with accounting through the paper transactions that originate or pass through the purchasing department and supply original information for certain of the accounting records.

PURCHASING DEPARTMENT ORGANIZATION.—The purchasing department organization in a small or medium-sized company will consist of: purchasing agent, buyers or assistants to purchasing agent, follow-up section, perhaps an invoice section, and a clerical force. In a large company, the organization may consist of: purchasing agent (sometimes known as director or manager of purchases, or general purchasing agent), buyers, junior buyers, and a general service section (under the direction of a purchasing office manager) which will be subdivided into a correspondence unit, follow-up unit, price-checking unit, file unit, stenographic unit, and mail room, each headed by a unit head responsible to the purchasing office manager. In such an organization, the purchasing office manager reports directly to the head of the purchasing department and the service section handles all matters regarding purchase orders occurring subsequent to the placing of the order, but in cooperation with the interested buyer and subject to his direction so far as any action affecting vendor relations or purchasing policies is concerned.

Purchasing Agent.—The purchasing agent should be selected with careful regard to his ability, personality, versatility, and breadth of vision. He must be, at one and the same time, an organizer and leader

for his department, a worthy representative of the company in its contacts with other concerns, a keen student of business, a man capable of consideration and prompt decision, and one having balanced judgment and clear foresight. He should be of the executive, not the clerical or mechanical, type, although insight into clerical, accounting, and mechanical problems is an asset.

Much of the purchasing agent's success will depend on the skillful use of purchasing psychology. Edward G. Budd, Sr., President of the Edward G. Budd Manufacturing Co., has long emphasized the importance of treating salesmen so that when they secure new price concessions they will immediately notify the purchasing agent so that he may get the benefit. Purchasing agents of long experience reemphasize the wisdom of being a good listener. And while lavish entertainment by salesmen is flattering, it may spoil the competitive situation with reference to a buyer.

Responsibilities of the Purchasing Agent.—The principal responsibilities of the purchasing agent are:

1. Keeping up the company's standard of quality production by his share in the choice of materials used.
2. Organizing and directing the purchasing department and acting as sole head of its personnel.
3. Spending a large portion of the company's money and being responsible for its wise expenditure.
4. Preserving the operation of the company's production schedules without interruption.
5. Representing the company in one branch of its major contacts with other firms.
6. Maintaining the company's reputation for integrity and fair dealing by his method of negotiating with vendors.
7. Acting as an executive of the company and a partner in its councils, particularly in preparing the purchase budget.
8. Keeping the company in step with progress by research and open-mindedness on new materials, new tools, etc., for which he is looking constantly.
9. Acting as final check, in the interest of economy, on necessity for all goods requisitioned, questioning need, quantity and quality specifications.

These functions are in large part deputized by him to members of his department. In some small plants the purchasing agent retains responsibility for keeping in touch with and signing all contracts.

The purchasing agent's actual personal duties are as follows:

1. Interviewing salesmen to obtain up-to-date information, securing and comparing quotations, and placing orders for such main commodities as he shall reserve to himself to purchase.
2. Establishing purchasing policies for his department to execute.
3. Preparing, or at least overseeing, all general reports on purchasing presented to management.
4. Conducting all major adjustment negotiations which are sufficiently vital to affect his company's goodwill.
5. Taking part in interdepartment conferences whether for planning, formulating of company policies, or other purposes.
6. Approving material specifications on major commodities.
7. Supervising other functions of his department.

Assistant Purchasing Agent.—The assistant purchasing agent is, under the purchasing agent's supervision, responsible for aiding in the

operation of the department and for the purchase of that group or class of purchased goods assigned to him. His duties in the latter capacity are to inform himself thoroughly about the market and manufacturing conditions of the class of goods so assigned, to interview salesmen, to secure and compare quotations, and to place orders for all materials intrusted to him. In a smaller company he usually conducts correspondence as to shortage, defect, and adjustments and, in some companies, as to follow-up on orders. When general service or follow-up sections are maintained, the respective correspondence duties may be delegated to these sections.

Buyers.—The buying section in a centralized purchasing department includes the purchasing agent, his immediate assistants, and a number of buyers. Items to be purchased are divided between buyers by types of material rather than by point of use or any other consideration. For example, a large purchasing department might have a buyer of ferrous metals, of nonferrous metals, of tools, of stationery and supplies, of textile products, and so on. Division of items to be purchased by this

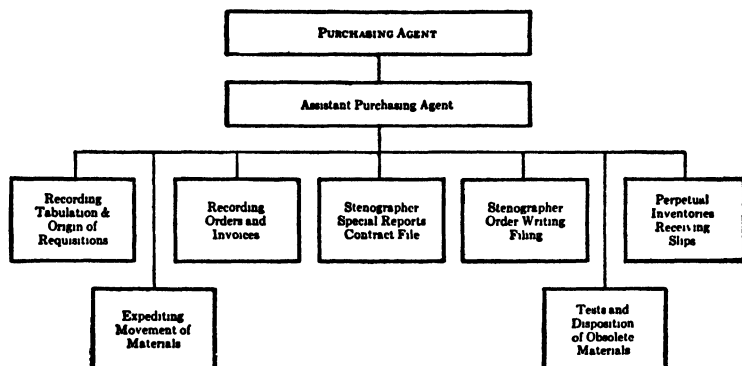



FIG. 3. Organization of Purchasing in a Company with More than One Plant (Shoe manufacturer. Purchasing centralized. Purchases less than $5,000,000 per year)

(Handbook of Purchasing Policies and Procedures, vol. 1, N.A.P.A.)

method allows specialization on correlated materials, reports on which are generally grouped and analyzed together in trade papers, forecasts, etc. It also provides for opportunity to acquire acquaintance with the vendors' representatives and the vendors' plants by continued interest in, and association with, the same type of materials.

In some organizations the purchasing department may be set up on a **divisional or functional** rather than a commodity basis. In that case, one buyer would handle all purchasing for a particular division or function of the business. The theory behind this plan is that the buyer thus becomes familiar with the particular needs and specifications of that division and learns to work with the plant organization responsible for that function. This plan also eliminates separation or double handling

of requisitions containing several items belonging in different commodity groups. Except under unusual conditions, however, commodities, rather than divisions or function, should be the basis of buyers' assignments. Otherwise, duplication of effort and loss of total purchasing influence in the commodity field are inevitable.

The **number of buyers** will be controlled by volume of purchases and variety of materials purchased. In a company of moderate size, the purchasing agent may have but one assistant purchasing agent or buyer. Even here it is desirable to follow the plan of division of the buying task by class of materials, the purchasing agent to handle those items which are of major importance, either for the value involved or for some other reason, and to delegate the buying of less important items to his assistant or buyer with such safeguards as may be necessary to cover the individual case. It is usual for the purchasing agent in a machine shop, for example, to buy coal, fuel, lubricants, and those raw materials used in large volume, while an assistant buys maintenance, stationery, and mis-

Group A

Lumber (including poles, ties, etc.); wooden crates, packages and packing.
Woodwork (turned and constructed); wooden ware (including bobbins, reels, etc.); wood patterns.
Castings, bolts, nuts, washers, rivets, screws, screw-machine work, drop forgings.
Construction materials, factory supplies (except coal and petroleum products), painters' supplies, chemicals.
Leather (including all kinds of belting), hardware, glass, insulation, polishing and grinding supplies.
Coal, oils (petroleum products including greases).
Small tools.
Stationery, furniture, office supplies, printing paper, rope, twine, janitors' supplies.
Large tools and machinery; steam, gas and water supplies; transmission machinery and appliances.
Nonferrous metals including wire; special nonferrous parts (punched, drawn, stamped, die-cast, or assembled).
Sheet steel (all grades); wire (iron and steel); bar steel; steel shapes
Pig iron; coke; limestone; foundry supplies.

Group B

Abrasives
Asbestos
Building Materials
Ceramics
Chemicals and Acids
Coal and Coke
Electrical Supplies
Factory Supplies
Furniture and Fixtures
Greases
Gums, Waxes, and Compounds
Hospital Supplies
Insulating Material
Leather Supplies
Machines—Parts and Machine Tools
Metals—Ferrous
Metals—Nonferrous
Oils
Paints and Varnishes
Paper and Products
Precious Metals
Precious Stones
Printing
Rubber
Supplies—Office and Janitor
Textiles
Timber Products
Tools
Vehicles and Accessories
Wearing Apparel

FIG. 4. Grouping of Materials and Supplies for Purchasing

cellaneous supplies which involve the larger number of contacts but lesser financial commitments. Fig. 3 shows the organization of a typical purchasing department for a small or moderate-sized organization.

In **assigning commodities to be purchased** among buyers, it is well to have in mind groupings which have market tendencies in common, and which are capable of being studied together to the best advantage. The related use of products may also be a factor in combining them for buying purposes. How far such grouping should be carried is affected by volume of purchases of various items, total volume of purchases, size of organization, and many other factors, and must be worked out to meet conditions in the individual case. Fig. 4 illustrates a method of grouping items to be purchased by a single buyer, showing two examples of different types of grouping.

Follow-up Section.—The duties of the follow-up section are to see that all goods ordered are received in time for requirements or in accordance with specified delivery dates and to have always on its record a definite acknowledgment of each order and promise of delivery.

Clerical Force.—The duties of the clerical force are to record purchase orders, invoices, and receipts, to keep all necessary departmental or interdepartmental records, and to do the necessary typing, checking, and filing. Clerical work in the purchasing department should be directed and checked in exactly the same manner as any other clerical routine.

Purchasing Office Manager.—The purchasing office manager in a large organization supervises the entire correspondence and clerical function of the department. Under such circumstances, the necessity of his close cooperation with buyers is obvious. Often he is entirely responsible for all relations with the personnel department in relation to the hiring and supervision of all department personnel except buyers. Fig. 3 shows a detailed organization chart for a representative purchasing department in a well-organized company.

Purchase Budgets and Policies

THE PURCHASE BUDGET.—The purchase budget is the purchasing department's plan or schedule of operations. The purchasing department's function in budget preparation is to combine estimates of use as submitted by the production department and a statement of inventory now carried as submitted by the storeskeeping or materials control departments, with the purchasing department's special knowledge of market conditions, so as to form a workable plan for procurement of materials needed—and no more—in time for production requirements, and at the least possible cost in inventory investment consistent with purchasing under favorable market conditions.

The following **responsibilities** are involved:

1. To advise as to the period in advance that should be covered by the commitment.
2. To determine, with the cooperation of the production control and stores departments, the amount of stocks to—
   a. Protect production schedules.
   b. Keep from paying a high bonus for rush shipments.
   c Keep inventories down to prevent excess carrying costs.

Items in the purchase budget with regard to a program for a production period are:

1. Estimated use (furnished by the production control department).
2. Quantities on hand (furnished by the materials control or stores departments).
3. Time required for delivery from vendor (furnished by purchasing records).
4. Probable price variations or market trends (furnished from purchasing department data or charts).

From these four elements the purchasing department can plan its purchases, according to market trends, seasonal variations, etc. It may contract for a reasonable period in advance, specifying deliveries on schedules consistent with use, state of inventory, and necessary time allowance for delivery, with due consideration to margin of safety for emergency demand, spoilage, transportation delays, and the like.

ADVANTAGES OF THE BUDGET.—The purchase budget is an important factor in efficient purchasing. It tends to eliminate costly emergency orders, and allows full advantage to be taken of price movements. It also makes possible quantity purchasing—with its consequent advantages—on deferred deliveries. It is a statement of the probable future need for materials and supplies, and the further ahead its estimates are made, the better will be the plans for meeting the demands. The length of time covered by the estimates depends entirely upon the item estimated. In some cases it may be as short as 30 days and in others several years. The important point is that the purchasing department must have knowledge of the needs for the various materials and supplies purchased as far in advance as possible. In contrast with this understanding of the budget as a plan, is the definite authorization to purchase, which covers a limited period only.

CHECKING BUDGET PERFORMANCE.—The purchasing agent must have the authority to check frequently the record of performance against the purchase budget and to suggest its revision on the basis either of performance or of altered purchasing conditions. Particularly in times of unusual economic stress or change, the continuing advice of the purchasing agent in continuing or revising the budget is essential.

PURCHASING POLICIES.—The primary objectives of the purchasing department are threefold:

1. To procure the necessary materials, supplies, etc., of proper quality.
2. To procure them in time for plant requirements and have them delivered to the proper place.
3. To procure them at the lowest possible ultimate cost.

To state these factors as a single objective: the task of the purchasing department is to have on hand necessary goods to insure uninterrupted production of a product of satisfactory quality at the lowest possible expense. More briefly summarized, it is to obtain what is wanted, when it is wanted, where it is wanted, of the right quality and at the right cost.

COSTS AND SAVINGS.—Upon analysis, the above objective becomes entirely a matter of **ultimate cost.** Interruption of operations and poor quality of materials are undesirable because they add to cost. Cost

must not be confused with price, because the price of materials is only one element in the cost of purchasing. Departmental expense, costs of errors and losses, cost of carrying inventory, cost of interruption of production, go with the price paid for purchased goods to make up the ultimate procurement or purchasing cost. The fundamental plans, then, must contemplate economy in departmental expenditures, elimination of errors, losses, and interruptions, a low inventory and a low purchase price as the ideal. The size of the department and its consequent expense and the elimination of losses are matters of departmental efficiency rather than of policy. Inventory and prices paid for materials, however, are items of policy.

The purchasing department must **weigh the savings** to be effected by buying in quantity at low spots in commodity markets against the expense of carrying excess quantities over immediate requirements in inventory until used. Determination of a purchasing policy involves: (1) knowledge of carrying-cost of inventory; (2) forecasting of trends in commodity markets. Ordinarily, inventory carrying charges will more than counterbalance possible savings in price on items whose market prices are stable to a degree. On many commodities, market changes cover a wide range, sufficient to make savings from purchases spotted at low points in the swing outweigh the cost of carrying a large inventory.

TWO PHASES TO POLICIES.—There are, therefore, two phases to purchasing policies:

1. On items on which price changes are narrow, purchases should be strictly in accordance with estimated use, and no further covering should be done other than to insure a reasonable margin of safety for uninterrupted operation.
2. On items on which market changes are wide and frequent, the policy should be to buy at low points in market movements for periods dependent upon the extent of swing and the forecast of use.

Inventory carrying charges for average warehouse stocks including desirable and active items are set by Parrish at 25% per annum. The division of this percentage is as follows:

Item	Per Cent
Storage facilities	.25
Insurance	.25
Taxes	.50
Transportation	.50
Handling and distribution	2.50
Depreciation	5.00
Interest	6.00
Obsolescence	10 00
Total	25.00

Parrish points out that depreciation, including deterioration, obsolescence, shrinkage, and perverted or uneconomical use, and expense, including extra handling, accounting and miscellaneous costs, in addition to those mentioned, are higher for undesirable than for active items. He, therefore, recommends as conservative for excess or undesirable items a rate of depreciation of 20%. It is obvious that the cost of carrying inventory will vary greatly as to different classes of material. Each company should make its own estimate based on its own experience of handling and storage charges, and losses from depreciation, obsolescence, etc.

LONG-TERM BUYING POLICIES.—Policies for long-term buying can be adopted safely only on the basis of an ample statistical background, which depends upon records gathered from the past experience of the purchasing department, market reports, government data, business forecasts, etc. Market statistics are available in trade papers, special reports, and in some cases in government publications. They include production figures, stocks on hand, current rate of operation, unfilled orders, and other indications of probable price change or stability. Price movements may be followed through charts published in trade papers, or through charts maintained in the purchasing department. The latter are preferable since purchases may then be spotted on the charts to indicate the success of the department in buying at a saving.

Taxes and other governmental action, actual or contemplated, may be factors in buying policy. At times, also, the continuation versus the possible interruption of sources of supply may determine the policy.

Seasonal trends should be noted and allowance made for them in planning policies regarding commodities affected by the seasons. **Cyclical trends,** or variations in the business cycle, are interesting and often suggestive. For forecasts, it is advisable to depend rather on actual data than on the continuation of a line in a cyclical graph. **Secular trends,** or long-time tendencies, must be weighed, and in some instances even weather forecasts and style changes are strong indications of the buying policy to follow.

Vendors from whom goods are purchased are necessarily familiar with conditions in their trade. Information from sources of supply is one of the best indications of the wisdom of buying for the future.

USE OF GRAPHICAL METHODS.—It is strongly recommended that graphs be maintained for presentation in a comparative form of various items of information on which a purchasing policy may be based. On these charts performance of actual purchases should always be indicated in comparison with statistical information on which purchases were based. This comparison is not merely a guide to future action, but also a valuable part of the record which proves or disproves efficiency of the buying done.

It would be gratifying to be able to advise some general principle of purchasing policy, possibly on the theory of cyclical movement, by which the purchasing department could refrain from buying at peaks in general movements, buy only from hand-to-mouth on the down curve, begin to accumulate stock on the bottom arc, and buy heavily on the upswing. It is safer, however, to limit any definite application of such a purchasing policy to the individual commodity to be bought.

Methods of Purchasing

CLASSIFICATION OF PURCHASES.—Purchases may be classified according to type of goods to be bought, and these classifications affect methods of purchase. There are four general classes: raw materials, supplies, fabricated parts, and machinery and equipment.

Raw Materials.—Raw materials are basic, unfabricated materials bought in large quantity. They include such items as pig iron, copper, lead, tin, cotton, rubber, lumber, sand, leather, steel (except in fabri-

cated forms), etc. In the main they are materials from which products are fabricated. Coal, coke, and fuel oil should be included with raw materials. Although they do not enter directly into the product, the methods and conditions of their purchase and their nature classify them as raw materials.

Raw materials as a rule are bought in carload lots and usually contracts are made covering requirements for a considerable period. Prices are governed by quotations in commodity markets, and are subject to rapid and wide change. The use of raw materials in a plant is relatively constant, quantities bought are large, and information indicating price trends is readily available. Such materials, therefore, lend themselves readily to forward-buying in anticipation of future needs. They should be bought on specification by chemical analysis or physical characteristics. It is the practice in the automotive industry to buy material to do the job rather than by physical specifications. For example, steel is purchased to make a certain fender, and so on. Raw materials are bulky, so that storage space is an item to be considered. Transportation rates and handling charges form a large part of their cost.

Supplies.—Supplies are the many items necessary for the operation and maintenance of plant, shipping department, office, etc. In general, they are items which do not enter into the product, but which are necessary in operation. They include stationery, electrical supplies, pipe and pipe fittings, shipping containers, belting and transmission supplies, bolts, nuts, washers, screws, packings, lubricants, hardware, abrasives, etc.

The purchase of supplies is characterized by the presence of many small items which, generally speaking, are standard items of manufacture, subject to published lists and discounts, though there may be specialties among them. There is little occasion to buy supplies for future requirements. Storage space is not a factor, but the clerical labor of checking, storeskeeping and accounting is great because of the variety of items in comparison with the value involved. They are usually requisitioned by the stores department. Standard specifications for such items are numerous.

Fabricated Parts.—Under the designation of fabricated parts are included parts and small tools or accessories which are bought for resale, either as a part of the product manufactured, or in connection with it. This class may include bearings, chucks, abrasive wheels, pumps, wrenches, tools, etc. It also includes special small parts which can be manufactured elsewhere more profitably than in the plant. Purchases of fabricated parts should be made on competitive quotations which, wherever possible, should be checked against shop estimates for making the same parts in the plant. The chief factor in such purchases is the margin of resale profit in the transaction. In the case of standard catalog items so purchased, the purchasing department is entitled to jobbers' prices. Future buying should be closely limited to the needs indicated by known production schedules.

Industrial Equipment.—Equipment items include machine tools, furnaces, boilers, automobiles, trucks, blowers, safes, and all such other major items bought for the plant or office. Equipment purchase requisitions should be approved by the management before being handled by the purchasing department. Technical considerations are supreme in

buying equipment, and such purchases should be covered by careful specifications, preferably by a description of purpose and result or performance demanded.

PURCHASE METHODS.—Methods of purchase vary according to the nature of demand in the plant and conditions in the market in which goods are to be bought. There are seven principal purchasing methods:

1. Purchase strictly by requirements.
2. Purchase for a specified future period.
3. Market purchasing.
4. Speculative purchasing.
5. Contract purchasing.
6. Group purchase of small items.
7. Scheduled purchasing.

The first four of these methods are classified by the factors entering into the determination of the time to buy, the quantity, and the duration for which the purchase is made. The last three are classified by the form of the purchase itself. Consequently these methods overlap. Contract purchasing may be market purchasing, purchase for a specified future period, speculative purchasing, or even purchase strictly by requirement. The same is true of scheduled purchasing and, to a lesser degree, of group purchasing.

Purchasing by Requirements.—Purchasing by requirements means that no purchase is made until a need arises, and then sufficient is bought to cover the existing need and no more. This method applies principally to emergency requirements, or to goods used so infrequently that they would not be stocked. It is essentially emergency buying and ordinarily makes the procurement of the goods the sole, or at least outstanding, requirement. The task of the purchasing department is to have vendor connections that can be depended upon to fill such orders promptly, and without taking advantage of the situation.

Purchase for a Specified Future Period.—Purchase for a specified future period is standard practice for buying goods regularly used, but not in great quantity, and on which price variations are negligible. Most supplies are bought by this method. The period for which the purchase is made may be fixed by a production schedule or by the stores record of past use or by a combination of both. Savings to be gained by the purchase of a given quantity also affect the determination of the period, as does the cost of carrying the items in inventory. It is important to note that no fixed periods should be set for all purchases, but that a separate and flexible period should be set for each item.

Purchasing According to Market.—Market purchasing is defined as purchasing according to condition of the market, to take advantage of price fluctuations, rather than in strict accord with a prearranged program or for a specified period.

So long as market purchasing conforms to the production schedule and its possible changes, or to the demands of the plant or business, it cannot be classed as speculative purchasing. It is entirely possible to purchase wholly with reference to demand, and yet take reasonable

advantage of market fluctuations. This procedure is followed in the case of railroads, public utilities, and some manufacturing corporations, which have definite construction or manufacturing programs mapped out for long periods ahead. By constant study of market statistics and factors that affect prices, an efficient purchasing department will be able to forecast the trend of market prices and buy to best advantage. When its studies indicate that the price range is at a reasonably low point, and that the future trend will be toward higher levels, the purchasing department will cover its requirements for a considerable period ahead. If indications are that prices are close to peak, and that the trend will be downward, a hand-to-mouth purchasing program is indicated until prices have become stabilized at a lower level. There are cases where it is possible to do market purchasing and not take spot delivery or make immediate payment. This condition applies especially to fabricated, or partly fabricated, materials where the fabricator can "cover" at an advantageous price for his raw materials, but does not want to make a commitment without being sure of an outlet for at least part of his finished goods.

Market purchasing applies to the buying of coal, coke, pig iron, and raw materials generally.

Advantages of this method are:

1. Large savings in purchase prices.
2. Greater margin of profit on the finished product, the price of which does not fluctuate as does that of the raw material.
3. Consolidation of purchases of a given material into one transaction with resulting saving in purchase expenses.

Disadvantages are:

1. Higher inventories with consequent higher carrying charges and tying up of storage space.
2. Liability to obsolescence in case radical changes are made in specifications.
3. Possibility of error in judgment of market tendencies, which may mean large losses.

Speculative Purchasing.—Strictly speaking, speculative purchasing consists in buying, when the market is low, more than can possibly be used in manufacturing, with the idea of later reselling much of the material at a considerable price advance to users who may come on the market when the price is high. The term, however, is often applied to a more-than-normal purchase risk in acquiring an excess of materials on low markets in the belief that the price will advance very substantially, thus saving the company considerable money. It goes a step further than market purchasing, makes price trends in commodity markets the primary factor, and gives less regard to a fixed program of use as a basis for buying. It does not base decisions on demands of the business itself, but on the possibility of market price savings. In some industries the cost of a single raw material alone is more than 50% of the total cost of production, as in some branches of the textile industry. Cost of cotton, for instance, outweighs all other elements of cost in producing cotton cloth. Here a saving of a few cents a pound on raw cotton offers a greater chance of profit than does any other activity of

the business. In such a case successful speculation is often a primary means of earning dividends.

Speculative purchasing is not properly a function of the purchasing department. It should be authorized only by direct action of a financial executive or the directors. The purchasing agent should present the full facts including hazards as well as possible advantages, together with his conclusions as to the advisability of taking the gamble. For ordinary manufacturing, the method is to be discouraged. Its single advantage is the possibility of huge speculative profits. Its **disadvantages** are many, including:

1. Tying up large amounts of capital.
2. Endangering the manufacturing schedules by waiting for profitable buying points.
3. Using large storage spaces.
4. Running the risk of obsolescence in case of radical change in specifications.

Contract Purchasing.—Contract purchasing offers advantages comparable to those of market or speculative purchasing without some of the latter's disadvantages. By a contract calling for deferred delivery over a period, advantage can be taken of low prices in effect on materials at the time of placing the contract, while spreading delivery of the materials over a schedule consistent with estimated future requirements. Thus the price advantage is obtained, without adding unduly to inventory. When contracting is possible, it should be done in cases of raw materials fluctuating widely in price from time to time, although often contract prices will not be as favorable as prices for spot purchases of the same quantities. Sometimes contracts are made to purchase items at current prices with a fixed top price.

Contract purchasing may be a means of **assuring continuous supply** as well as a method of getting price advantages. It then becomes applicable to the purchases of parts, tools, etc. It is particularly helpful on these items where the production program is known, but the timing of it is not entirely certain. In effect it then becomes **scheduled purchasing,** as described below, but is embodied in contract form for the better protection of both vendor and purchaser.

Grouping Items.—Group purchasing of small items is an interesting development in purchasing with the possibility of large savings. Every purchasing agent finds that he must buy hundreds of small items, so trivial in value that the cost of placing an order often exceeds the value of the goods purchased. The problem then is to handle such purchases as quickly and as inexpensively as possible. The purchasing department must continually watch the items included in the group, as it often happens that the demand for an item originally in a group may grow so large that it should be removed from the group and bought as an individual item. Arrangements may be made to send orders for all such items to some certain dealer who agrees to handle and bill them at a fixed percentage of profit above dealer's cost, his cost records being open to inspection by the buyer on demand. A considerable saving in clerical and purchasing expense is achieved by this plan, or by annual quotations.

The method is used chiefly in such fields as pipe fittings, general hardware, electrical supplies, stationery, etc. Often the practice is to secure from a reasonable number of bidders their quotations on a list of these

small items with the understanding that the prices will be guaranteed on all requirements in the class of items covered for a period of three months. Then all orders go to the successful bidder without further inquiry or bid. An interesting variation is that some purchasing agents forward merely a copy of the requisitions to the supplier, to eliminate the expense of orders, and accept a single monthly bill to avoid the checking of multiple invoices.

Stores and production control departments can often simplify purchasing problems by grouping small items on their requisitions. The small order is one of the most costly elements in buying.

Scheduled Purchasing.—The schedule plan for purchasing materials used regularly in large quantities is one of the newer important developments. It was devised to reduce investments in stocks. Essentially it consists in giving suppliers approximate estimates of purchase requirements over a period of time, thus placing them in a position to be able to anticipate orders and be prepared to fill them when received.

Although **minimum inventory is probably the most important objective** in this plan, other objects sought after are good quality, timely deliveries, and low cost. Good quality can be obtained only by giving suppliers enough time to produce. Timely arrival of materials can be better assured by laying down in advance a definite material requirement. Low cost results from giving suppliers advance information as to requirements, thus permitting them to produce materials in the most economical manner.

The **danger inherent in this plan** is that requirements or specifications may be changed and goods made up or allocated but not now required may become a matter of dispute between vendor and purchaser. Scheduled purchases should be restricted, therefore, to items definitely known to be required within a closely limited period and should be established as to specifications. Also, the purchaser should make very clear in his correspondence the responsibility he assumes and the risk the supplier assumes.

Blanket orders are purchase orders placed and accepted for large quantities of materials to be delivered as later specified. By the agreement the vendor agrees to furnish and the purchaser agrees to accept a stated number of units, usually within a given period. Orders based on customers' requirements are characteristic of the automotive industry. The vendor is then in a position to manufacture or procure the full amount in the assurance that the purchaser will authorize shipment in due time. The blanket order saves some of the formality of the contract method and achieves many of the desirable features of scheduled purchasing, but with a greater certainty as to the legal rights involved. Blanket orders usually cover fabricated parts or tools and contain a binding price based on the vendor's best estimate of his costs and the desirability of having a certain outlet for his product.

Buying Proper Quality

PURCHASE SPECIFICATIONS.—Buying proper quality depends on: (1) having proper specifications from which to work, (2) placing the order with reliable vendors, and (3) checking material bought against

specifications. A specification is no more than an accurate description of material to be purchased. Definiteness tends to minimize costs.

There are many forms of specifications indicated by:

1. Brand or trade name.
2. Blueprint or dimension sheet.
3. Chemical analysis or physical characteristics.
4. Detail of material and method of manufacture.
5. Description of purpose or use.
6. Identification with standard specification known to the trade generally and to the vendor.
7. Sample.

Specification by **brand or trade name** places the buyer in entire dependence upon the vendor's reputation for quality. It should be used only in cases where the branded product has been found to be superior to all others for the purpose intended, or where it is deemed to be satisfactory but the formula of its composition is secret or unknown. It also may be used in cases of standard products used in unimportant processes or in small quantities, when the extent of use does not justify expense of investigation and detailed specifications. The purchasing department should attempt to have at least two, and preferably more, approved brands. There are comparatively few brands that do not now have a competitive or equal grade.

Specification by **blueprint or dimension sheet** is advisable in the purchase of tools and fixtures to be manufactured, to meet special requirements worked out by the engineering department of the purchasing company. Blueprints provide a safe and easy method of checking against specifications when tools are received and inspected.

Specifications by **chemical analysis or physical characteristics,** or both, are ideal for raw materials in the metallic class. Such specifications can be checked accurately by laboratory tests.

Specifications by **detail of material and method of manufacture** should be used rarely. Ordinarily the vendor, if he knows the use for which goods are intended, is in a better position than the buyer to determine the proper materials and methods of manufacture. Also, this type of specification sometimes requires inspection at the vendor's plant, which is expensive. It should be used in cases of very particular and special requirements.

Specification by **description of purpose or use** is highly effective. If the vendor is dependable and accepts such a specification, the responsibility is entirely his. This form of specification is the least difficult to prepare and is recommended especially in the purchase of machines or tools about which the purchaser has no particular technical knowledge.

Specification by **identification** with some standard specification already published and accepted, is a most satisfactory form of specification, provided such a standard specification exists to meet the purchaser's requirement and can be accepted without undue and unnecessary expense.

Specification by **sample** is not recommended except in cases where no other type of specification is possible. Samples are subject to physical change and their use as standards is often a prolific cause of dispute.

Requirements for an Industrial Specification.—There are certain requirements for an industrial specification for material. It should be:

1. As simple as is consistent with exactness. Unnecessary detail in the specification is expensive.
2. Identified, when possible, with some brand or specification already on the market. Special goods are expensive.
3. Capable of being checked. A specification is of value only so far as it is checked.
4. Reasonable in its tolerances. Unnecessary exactitude is expensive.
5. As fair to vendor as possible.
6. Capable of being met by several vendors, for sake of competition.
7. Clear. Misunderstandings as to specifications are expensive.
8. Flexible within the limits of the need it meets. Specifications should be rigid enough to insure getting the necessary quality, but flexible enough to allow improvement and progress in step with the results of research.

Where commodities purchased are covered by commercial standards, the purchaser's task is greatly lessened, since it is necessary only to specify the desired grade according to the standard and the seller may guarantee conformance. Frequently provision is made for a certifying label as an assurance to open-market buyers. These labels normally state the name of the guarantor, commodity and grade covered, name and number of the commercial standard, and a definite, concise guarantee of conformance to all requirements.

Federal specifications can be secured from the Bureau of Standards of the Department of Commerce, Washington, D. C., which publishes a directory of such specifications. Many agencies prepare specifications which are largely accepted by manufacturers. Among these are: American Society of Testing Materials, Underwriters' Laboratories, American Society of Mechanical Engineers, etc. The amount of standard specification material available to the purchasing agent is great and always growing. No purchasing department library is complete without references to the various directories of specifications and copies of individual specifications applying to the particular industry.

INSPECTION AS A CHECK UPON SPECIFICATIONS.—All products ordered according to specifications must be reasonably checked. Inspection is not a function of purchasing, but the purchasing department should demand adequate inspection.

Buying the Proper Quantities

FACTORS DETERMINING THE QUANTITY TO BUY.—The physical factors in the analysis of when and how much to buy, according to the method developed by Davis, are graphed in Fig. 5, to which the following definitions of terms apply:

S = Rate of consumption of material, units per year
T_1 = Procurement time, in years, between placing order and receiving material
T_2 = Time (in years) in which the lot to be purchased will be used up
R_1 = Theoretical quantity constituting the order point—just enough material to last until new shipment arrives in the time T_1

R_2 = Cushion, or reserve, stock to keep on hand to allow for delivery delays and give also an additional amount for unexpected increase in use of material, extra waste or spoilage, etc. It is also the minimum stock.
R = Actual order point in units of material on hand and available, sum of $R_1 + R_2$
Q = Quantity in the purchase lot
M = Maximum stock, when new shipment arrives, sum of $Q + R_2$

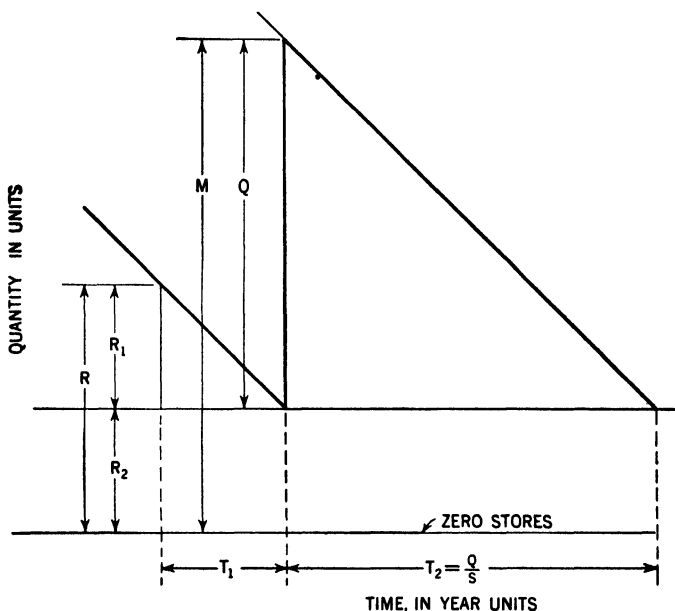



Fig. 5. Graphical Analysis of When and How Much to Buy

If, now, the following conditions apply to a certain material, what is the proper quantity to purchase from a vendor, and how soon should the purchase order be issued?

750 = Amount on hand, in units
3 weeks = Delivery time
4 weeks = Cushion stock supply to allow for unexpected emergencies
300 = Average rate of use per month in units
17 weeks = Maximum supply to be on hand

The amount on hand, 750, divided by 300, rate of use per month, gives 2.5 months' supply, or 2.5 × 4.33 (average weeks per month) = 10.825 + weeks' supply on hand, say 11 weeks. Four weeks' cushion stock is kept and 3 weeks' time is required for delivery. So the purchase order

should be placed in 11 − 7 = 4 weeks. The order point, therefore, is reached when the quantity on hand and available falls to $7 \times \frac{300}{4.33}$ = 485 units. Since the maximum quantity to be carried is 17 weeks' supply, or 1177, including 4 weeks' cushion stock, the quantity to order is 13 weeks', or 3 months', supply, which is 3 × 300 = 900 units. Thus the material will be ordered four times per year. The minimum stock is

$$4 \times \frac{300}{4.33} = 277 \text{ units.}$$

The above figures have not taken into account a calculation of the economic purchase lot, which, besides serving production needs and providing proper cushions and order points, also introduces the analysis of discounts or reduced unit prices on quantity purchases versus the costs incurred in the owning and storing of the material. In determining the economic purchase lot size for an item there are a number of factors to take into consideration:

1. Quantity on hand and available (not apportioned) in stores.
2. Rate of use, and whether use is steady, periodic, or irregular.
3. Time required for delivery of new lot (included in preceding discussion).
4. Amount to be kept as a cushion or reserve in case of delayed delivery (included in preceding discussion).
5. Amount to be kept for emergencies such as a jump in demand, excessive spoilage in processing, desire of sales department to build up extra finished stocks, etc.
6. Length of manufacturing period which it is desired to protect by having materials on hand.
7. Quantity discount obtainable on large lots.
8. Rental cost of storage area occupied.
9. Amount of working capital tied up and loss of earnings on this capital.
10. Other costs and losses in owning materials—taxes, insurance, depreciation, obsolescence, extra handling, etc.

ANALYTIC METHODS FOR DETERMINING LOT SIZES.— Mitchell (Purchasing) and Alford (Principles of Industrial Management) have developed analytic methods for the purpose of calculating the least-unit-cost lot. Fig. 6 plots the result of one analysis of this kind in a particular case.

The following analysis gives a rough approximation of the quantity to buy under conditions such as stated and is a rough-and-ready method to employ.

Assume that the following conditions exist in regard to a certain material or part carried in stores, and that the time to reorder and the amount to buy is to be determined:

On hand and available	300 units
Needed within next 30 days	150 "
Normal constant demand per month	100 "
Time required for delivery of a lot	1 month
Minimum reserve stock allowance to protect against failure of delivery, period to cover	1 "
Additional allowance for possible increased use, spoilage, losses, period to cover	½ "

The 300 units on hand and available will take care of the next 30 days' needs of 150, reducing the stores to 150, or 1½ months' normal supply. But it takes 1 month to get a lot in, and just before this lot arrives there should remain in stock 100 (1 month's use) to protect against delivery failure, and 50 (½ month's supply) to protect against increased use, spoilage, etc., or a total of 150 units. Thus, $300 - 150 = 150$ is the

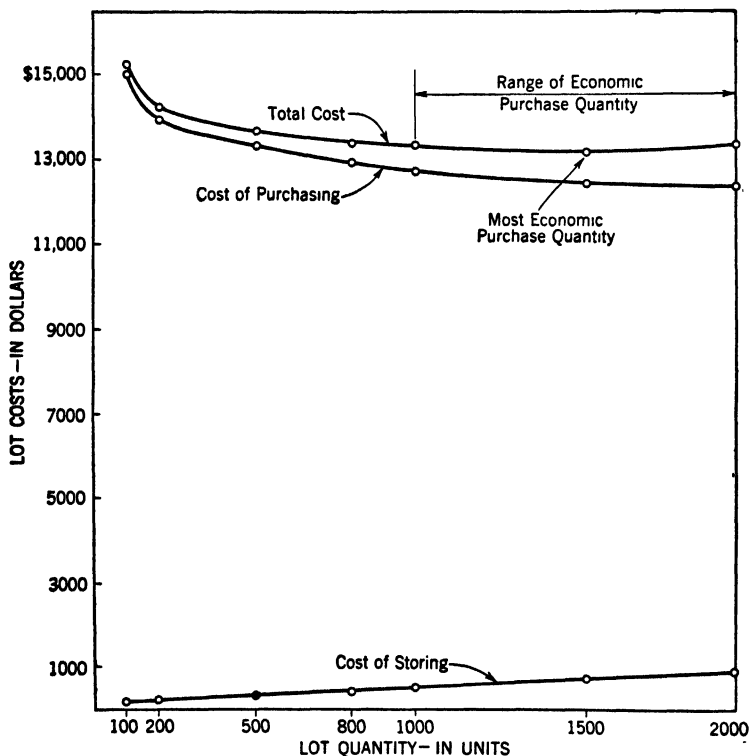



FIG. 6. Curves Marking the Range of Economic Purchase Lots for an Item

amount on hand in excess of the delivery reserve and extra reserve allowance, and this amount is just enough to take care of the next 30 days' needs. So, since a month is required for delivery, an order must be placed at once for the next lot. If the item is not too costly, and prompt delivery is not always assured, the order may be placed for, say, a 6 months' supply, or 600 units. When this lot arrives there will be $600 + 150 = 750$ units in the storeroom.

MINIMUM ORDERING QUANTITIES.—A determination of the minimum ordering quantity in a case of the above kind could be made as follows:

Supply for demand during period up to delivery.....	+150 units
Supply for demand for period during delivery of next lots	+100 "
Margin of safety..................................	+ 50 "
Present surplus over demand (or, if there is an excess of demand over supply, use as a + quantity)......	−150 "

The net result of this calculation is that $150 + 100 + 50 - 150 = 150$ is the minimum quantity which could be ordered and still keep demand supplied.

Minimum quantities would be ordered only when there is no appreciable saving obtainable by quantity orders, when the current price is high or fluctuates widely and a drop is expected, and when delivery is easy to secure from any one of several assured sources. As previously pointed out, excess quantities, while bringing some saving in quantity discounts, also entail carrying and storage costs which may run up to 25% of the purchase cost, or about 2% for each month in which the inventory is carried. Each company must determine the approximate percentage from its own data and experience on the various factors. A balance between these two conflicting factors is necessary to secure the greatest economy. There is a range of lot sizes within which the lowest total purchase cost is obtained, as already pointed out (see Fig. 6), and any lot within this range may be ordered with approximately the same savings.

PURCHASE LOT FORMULAS.—Formulas have been devised by a number of investigators to determine the quantity to buy to obtain the minimum unit cost and the quantity to obtain a desired rate of return on working capital. Such formulas have been developed by Davis, Lehoczsky, Pennington, and others. Being based on empirical data, these formulas give only approximate answers but so, also, do all other methods, and the results in every case must be subject to the exercise of judgment in purchasing. While their effectiveness is limited to certain cases, every purchasing agent should know about them.

Most Economic Purchase and Storage Lot.—Under the formula method developed by Davis, and referring to Fig. 5 and the symbols used in connection with it, the mathematical calculation (not given here) of the most economical quantity to buy from the standpoint of procurement, storage, and interest charges results in the following equation:

$$Q = \sqrt{\frac{G}{K + H}}$$

in which $K =$ An interest factor $= \dfrac{C'' I}{2S}$

and $H =$ A storage cost factor $= \dfrac{B E}{S}$

so that the above expression may be reduced to

$$Q = \sqrt{\frac{2GS}{C''I + 2BE}}$$

The terms employed are defined as follows:

Q = Total quantity to buy for the lowest unit purchase cost, in number of units

G = Total cost of preparing the purchase order, in dollars (purchasing department operating expenses, cost of forms and incidentals, outside purchasing expenses such as travel, any time spent by company executives in connection with the order, etc.)

S = Rate of consumption of material in units per year

C = Total purchase price of one unit of the material including freight charges, in dollars

I = Interest rate on money, in per cent and used as a decimal

B = Net storage floor area occupied by one unit of the material, in sq. ft.

E = Annual storage charge per sq. ft. of storage floor area, in dollars

The above equation gives the most economical quantity to buy at one time to get the lowest over-all unit cost of purchasing the material and carrying it in stores.

Purchase Lot for Highest Return on Working Capital.—It is often desirable to base the calculations on the quantity to buy to obtain the highest rate of profit on the working capital tied up in the purchase, rather than the lowest over-all unit cost of buying and carrying the material. The equation used under the highest-rate-on-working-capital plan is:

$$Q = \frac{2S\,[p - T_1\,(F - 1)\,Z]}{\cdot\,Z}$$

where p = Actual net profit desired on cost-ready-to-sell as the unit of material (or item) is later sold to the customer in the finished product, in per cent and used as a decimal

T_1 = Time required for delivery of a new lot, in years and expressed as a decimal

$F = R \div R_1$ = Ratio between actual order point, and theoretical order point (no cushion stock), both expressed in units of material

Z = Desired annual gross profit on working capital, in per cent and used as a decimal

Assuming now that a proposed purchase order is to be placed under the following conditions, what is the most economical purchase lot, and what is the lot to buy to obtain the highest return on working capital?

G = \$30
S = 8,000
C = \$.10
I = 5%
B = .02 sq. ft.
E = \$3

p = 5%
T_1 = 1 month
Z = 25%
R = 1,400
R_1 = 700
$F = R \div R_1 = 2$

The calculation of the most economical quantity to order, from the standpoint of quantity discounts and purchase cost versus storage carrying charges, is as follows:

$$Q = \sqrt{\frac{2 \times 30 \times 8.000}{.10 \times .05 + 2 \times .02 \times 3}} = 1,960, \text{ say } 2,000 \text{ or about 3 months' supply}$$

From the standpoint of desired rate of profit on working capital turnover, the approximate quantity to order would be:

$$Q = \frac{2 \times 8,000\,[.05 - 1/12(2 - 1) \times .25]}{.25} \doteq 1,870, \text{ say } 1.900 \text{ or a little less than 3 months' supply}$$

Under these computations it is evident that the purchase order would call for 2,000 units which would cost, delivered, $200.

EXAMPLES OF ECONOMIC PURCHASE LOTS.—Two examples illustrate the determination of economical ordering quantities:

Example 1. Commodity—Pig iron—2x grade.

Use per week	100 tons
Stock on hand	300 tons
Time required for delivery	3 weeks

Price of pig iron stable with no changes indicated. Carload shipments cost at the time $19 per ton delivered at purchaser's plant.

A bargeload of 1,000 tons can be secured at $18.50 per ton delivered, at the time.

Minimum ordering policy would dictate ordering to provide not over 8 weeks' supply, including margin of safety. This would mean an order of 500 tons, which, plus 300 tons in stock, gives an 8 weeks' supply.

Cost of carrying additional 500 tons, or additional 5 weeks' supply, at carrying charge of 25% per annum on 500 tons at $18.50 per ton, equals $133.41.

Saving on 1,000 tons at $.50 per ton equals $500.

Advisability of bargeload purchase is clearly indicated.

Example 2. Commodity—General purpose machine oil.

Use per week	5 bbl.
Stock on hand	15 bbl.
Time required for delivery	2 weeks

Delivered price, including transportation on less than carload shipments, $7.15 per bbl. Carload of 60 bbl. can be secured at delivered price of $6.90 per bbl.

Minimum ordering policy would indicate ordering to provide for 5 weeks' demand, including margin of safety. This would mean an order of 10 bbl., which, plus 15 bbl. in stock, gives 5 weeks' supply.

Cost of carrying additional 50 bbl., or additional 10 weeks' supply, at 25% per annum equals $16.

Saving on 60 bbl. at $.25 per bbl. equals $15.

The indication is that buying the carload quantity is not advisable.

A record of economical ordering quantities is desirable. There is no necessity for working out these quantities on every purchase, though they should be open always for consideration as conditions change. Stores

Commodity	Unit
Acids	Pound
Alcohol	Gallon
Aluminum—sheets, bars, etc.	Pound
Asbestos	Square yard
Asphaltum	Pound
Babbitt metal	Pound
Bands for cotton bales	Pound
Belt lacing	Each or foot
Belting	Foot
Boiler tube	Foot
Bolts	Each or 100
Brass—sheet, plate, tube, bar, etc.	Pound
Brick	1,000
Brooms	Dozen
Brushes	Dozen
Calcium chloride	Pound
Casks	Each
Cement	Bag or barrel
Chain	Foot or pound
Chalk	Pound
Chaplets	100
Charcoal	Bushel
Cloth	Yard
Coal	Pound or ton (2,200 lb. whsle.) (2,000 lb. retail)
Coke	Ton (2,000 lb.)
Compressed air	Cubic foot
Concrete work	Cubic yard
Copper rivets	Pound
Copper—sheet, bar, tube	Pound
Corks	Gross
Dirt removal	Cubic yard
Electric batteries	Each
Electric fuses	Each
Electric lamps	Each
Electricity	Kilowatt-hour
Emery	Pound
Emery cloth or paper	Ream or sheet
Emery wheels	Each
Enamels	Gallon
Excelsior	Pound
Felt	Square feet or pound
Fiber	By dimension
Files	Dozen
Fillets—leather	1,000 feet
Fillets—wood	100 feet
Fire brick	1,000
Flour	Barrel or bag or pound
Fusible plugs	Each
Gas	1,000 cubic feet
Gasoline	Gallon
Glass	Light and size
Glue	Pound
Grease	Pound
Hair	Bushel or pound
Hammers	Dozen
Hangers, shaft	Each
Heat	British Thermal Unit (B.t.u.)
Hinges	Pair
Hose	Foot
Hose clamps	Gross
Hose couplings	Dozen
Hosiery	Dozen
Iron (all forms)	Pound or cwt.
Lacquer	Gallon
Lamp black	Pound
Lath (metal)	Square foot
Lead	Pound
Leather	Pound
Lime	Pound
Lumber	1,000 board-feet
Mica	Pound
Nails	Pound
Naphtha	Gallon
Nipples	Each
Nuts	Pound
Oils	Gallon or barrel
Pails	Dozen
Paints	Gallon or pound
Paper	Pound or ream
Paper (roofing)	Roll
Pins	Gross
Pig iron	Ton (2,240 lb.)
Pipe	Foot
Pipe fittings	Each
Pitch	Pound
Printing	Per 1,000
Pulleys	Each
Red lead	Pound
Rivets	Pound
Rope	Pound
Rosin	Pound
Sal soda	Pound
Sand	Ton (2,000 lb.)
Sandpaper	Ream or sheet
Saws	Each
Screws	Gross
Shovels	Dozen
Steam	Pound
Steel	Pound or cwt.
Steel rails	Ton
Stone	Ton or cubic yard
Straw	Ton
Talc	Pound
Tallow	Pound
Tar	Barrel
Tin	Pound
Twine	Pound
Varnish	Gallon
Water	Gallon or cubic foot
Wax	Pound
Wire	Pound
Wood	Cord, or 1,000 board-feet
Woolen fabrics	Yard
Zinc	Pound

Fig. 7. Units in Which Different Items Are Ordered

records and purchasing records should contain, as an integral part of their information, the economical ordering quantity established on previous lots, and all the facts necessary to revise such figures. Fig. 7 gives units of measurement, weight, or volume, as established by custom, in which some of the more common commodities are bought and sold.

LIMITS ON QUANTITIES OR EXPENDITURES.—Sometimes maximum ordering quantities are set, in effect, by the management. Often authority of the purchasing department to buy is limited by a ruling that not over, say, 9 months' supply of any commodity can be bought ahead without special executive authorization. In other cases the limit to the purchasing agent's authority may be a dollar limit, whereby purchase requisitions amounting to more than, say, $25,000 or $50,000 must be approved by the general manager, president, or even the board of directors. Even when such limitations are not set by a higher authority, it is desirable that the purchasing agent should require his buyers to be limited by two factors: value of the purchase, and length of the commitment. For example, the purchasing agent may authorize a buyer to handle without further authorization purchases up to $10,000 but no higher, and future commitments that do not exceed 6 months' consumption.

Buying at the Proper Price

COMMODITY CLASSIFICATION.—The variety of items to be purchased, as to type, volume, and purchase conditions, requires that the purchasing department should build up a system of obtaining and recording price information in quickly available form. From the viewpoint of price, commodities may be classified as follows:

1. Commodities on which prices are established by market movements.
2. Commodities on which the price is given in catalogs and on discount sheets.

Price Established by Market Movement.—In the first group are commodities on which prices are established by market movements and information about which may be drawn from market reports, published quotations, etc. These commodities include the majority of raw materials, such as pig iron, steel in commercial grades, nonferrous metals, leather, cotton, rubber, and so on. The purchasing department follows market reports, trade papers, other sources of published information, and maintains charts or graphs on prices and conditions which govern prices, such as production, demand, etc. Daily reports are available in trade papers of metal industries and in general business dailies. In specific instances it is necessary even to have cabled or wired reports from the markets. A purchasing department library of information on such items should be built in accordance with the necessity for prompt and accurate data.

Even though items are covered by catalogs and price list, the buyer, in the case of important orders, should determine the factors that go to make up the price and, if conditions warrant, try for a reduction, not waiting for conditions to force a revised price. As an example, in New York City there is a fairly well-established price list on paper bags. The

major item of cost is kraft paper. When the market on kraft makes a steady decline, the buyer should not wait for a revised price list but should find a vendor who, because of small stocks, can give him a reduction on the price of bags warranted by the drop in the price of kraft paper.

There are many such commodities in which the price of the finished goods is dependent very directly on raw material prices. Some typical examples are steel drums (which fluctuate in price with the market on steel sheets), cardboard containers (which follow the market on chipboard or kraft), leather belting (which varies with the market on hides), and many secondary chemical products (which follow very closely the price of their chief constituent primary chemical). Other commodities depend on two or several primary constituents.

Price Data Given in Catalogs.—The second group consists of commodities on which prices are governed by issuance of catalog and periodical discount or net price sheets. This group includes most standard mill supply and hardware items such as regular drills, taps and dies, wrenches, and many commodities of this general type. The purchasing department must have a **catalog file,** and a **file of current prices on catalog items,** carefully indexed, and kept strictly up to date. The clerk or assistant responsible for catalogs and net prices or discounts should check his files with the vendor's at regular periods. All trade papers should be followed for news items as to new or revised publications, affecting items bought.

Catalogs should be filed in ample storage cabinets, drawers, or on shelves, and should be indexed by commodities. They should preferably be arranged under major commodity headings so that related subjects may readily be investigated. A typical division of a catalog file into classes follows:

Section		Section	
1	Metals (except steel)	6	Belting and transmission
2	Steels	7	Machinery and equipment
3	Small tools (taps, dies, drills, reamers, etc.)	8	Foundry supplies
4	Hardware	9	Machine accessories (chain, bearings, etc.)
5	Pipe-shop and plumbing supplies	10	Miscellaneous

Where buying is divided among several buyers, it is often the practice for each buyer to keep his own catalog and price file. It will be necessary, under any arrangement, for buyers to keep certain catalogs and price lists in their personal files, but it is desirable, even at expense of some duplication, to have a general catalog and price file under care of a clerk designated as price clerk.

ITEMS SUBJECT TO PRICE CONCESSION.—Even on cataloged items with standard price lists and discount sheets, it is frequently necessary to request vendors to supply quotations or new prices and discounts to keep price information up to date. (See Fig. 8.) The price clerk should file such information. All price files tend to get out of date. In the automotive industry it is considered worth while to add another buyer, if necessary, so that no one may have too many items to keep up to date.

Obtaining Competitive Quotations.—On special tools, forgings, castings, and many other items there are no market quotations or standard catalog prices and discounts available. To obtain proper prices, the purchasing department is dependent upon two factors: an understanding of the cost of items going into their manufacture, and competitive bids establishing the lowest price to be obtained. When large quantities of

CAD 2063
PRINTED IN U.S.A.

CADILLAC MOTOR CAR COMPANY
DETROIT, MICHIGAN

REQUEST FOR QUOTATION

GENTLEMEN:
KINDLY QUOTE US YOUR BEST PRICE, TERMS AND DELIVERY PROMISE ON THE FOLLOWING MATERIAL. PRICES QUOTED ARE TO REMAIN EFFECTIVE FOR 60 DAYS UNLESS OTHERWISE NOTIFIED
CADILLAC MOTOR CAR COMPANY

____

QUANTITY REQUIRED	NAME OF ARTICLE OR PART	PRICE	PROMISE DELIVERY AFTER RECEIPT OF ORDER

RETAIN THE DUPLICATE COPY OF THIS INQUIRY AND RETURN THE ORIGINAL WITH YOUR PRICES OPPOSITE EACH ITEM

BIDS WILL NOT BE EFFECTIVE UNLESS RETURNED ON THIS FORM.

WE EXPECT TO RECEIVE YOUR QUOTATION NOT LATER THAN________________

WE HEREBY AGREE TO DELIVER THE ABOVE ARTICLES AS SPECIFIED F. O. B.________________

AT THE FOLLOWING TERMS________________

SIGNED________________

DATE________________ ________________

THIS INFORMATION MUST BE GIVEN IF QUOTATION IS TO RECEIVE ATTENTION.

FIG. 8. Purchase Department Request for Quotation

such items are to be bought, a study is justified of material and labor costs going into their manufacture, to an extent sufficient to insure that prices quoted are fair and not excessive. On the large majority of such items, the only safe way to buy is by inquiry from a number of sources and comparison of competitive quotations.

To be effective in getting the best price, quotations should be:

1. Considered on a truly competitive basis. Award should be made to lowest bidder, except under unusual circumstances, such as doubts arising as to lowest bidder's financial ability or ability to complete on time or within specifications, or cases where the money value of

bids does not represent a proper comparison in the light of final cost.

2. Considered as final at the first figure submitted. Allowing of continual revision of bids or quotations after submission may bring a better price on that one transaction, but it militates against truly competitive quotations with the best obtainable prices in future transactions.
3. Considered as confidential by buyer. The policy of hinting to competitors of a bidder as to the nature of quotations destroys bona fide competition, and in the long run is expensive.

Quotations, after receipt and action, become part of the purchasing department information file in the hands of the price clerk. Losing as well as winning quotations should be recorded to give a proper price perspective on future purchases.

Buying at the Best Price.—The best assurance that the purchasing department can have that it is buying at the best price is mutual confidence between purchaser and vendors. Sales representatives are excellent sources of information as to price trends, contemplated revisions, and vendors' price policies. While price checks may be made periodically, it is, nevertheless, highly desirable that the purchasing department should choose and stay with vendors who have proved that they intend to give the buyer the best prices. There are many items to be purchased on which there is no available reliable price information, and the volume of which is insufficient to justify an exhaustive study of costs. Sometimes competition is impractical, either because of lack of time to secure competitive bids, or because of the fact that only one source of supply is considered capable, or because the transaction is of such a nature that open competition would disturb the market and bring about higher prices. In such cases dependence on sources of supply is the only course open to the purchasing department. A record of previous purchases of an item over a period, together with knowledge of changes in general conditions over the same period, offers a valuable means of price checking. "Price alone is not a sufficient reason for us to change a source of supply," in the words of one purchasing agent.

Bargain or Cut Prices.—Many "bargains" and "cut prices" are offered by houses which are not dealt with regularly. It is a safe rule to regard such offers with suspicion and demand of the supplier proof of the quality of goods and his credit standing. There are exceptional cases in which a purchasing agent has the opportunity to buy below the right price through some special concession. But as a rule, all that the purchaser can expect to do is to buy at the right price consistent with the volume of the purchase, the credit standing of the vendor, and market conditions.

Purchase Contracts

CONTRACT REQUIREMENTS.—Purchase contracts should always be reduced to writing. Verbal modifications of written contracts should be avoided. The contract should clearly set forth in definite terms what the agreement is as to quantity, specifications, price, terms, time, special conditions, inspection, guaranties, penalties.

Quantity may be expressed as a definite figure in pieces, pounds, or other unit, or it may be expressed as "purchaser's requirements, estimated at ...." Quantity may be expressed as a rate of manufacture to be maintained by the vendor or in terms of the stock he binds himself to keep on hand for the purchaser. It is common to have quantity expressed in terms of tolerances, by which the vendor agrees to furnish not more than a certain maximum, nor less than a stated minimum. A usual expression is "purchaser's requirements not to exceed ...." From the purchasing standpoint the more leeway allowed on quantity, to allow for possible error or change in estimate, the better the contract.

SPECIFICATIONS.—Specifications should follow the same rules laid down for buying specifications on a previous page of this Section. When specifications are vital and rigid, provision should be made in the contract for a clear and definite agreement as to the basis of inspection and rejection, where and how inspection is to be made, and what equipment or labor, if any, the vendor must supply to help make the inspection. Suppliers of creosoted products, for instance, to provide for inspection under certain specifications, must furnish a laboratory with certain equipment. High-tension insulators to meet certain specifications must be tested where certain voltage combinations are available. Such points must be known to the buyer and specifically covered by the contract, as they may be an item of cost overlooked by the supplier. In many cases inspection by an outside agency or company may be called for. In such cases the outside company should be named and clear provision made as to who should bear the expense of the inspection.

PRICE.—Price may be fixed at a determined figure by contract. In the case of goods whose price fluctuates beyond the control of the vendor, definite agreement on a fixed price cannot be had. In such instances it is often desirable to make the provision that price shall be based on market price at date of shipment, stating accurately the means of determining what market price is, such as the standard price reports in a reputable trade paper. When possible to do so, sliding-scale agreements should be safeguarded by inserting a maximum price above which vendor shall not charge, regardless of market changes. A most favorable type of price agreement is that by which vendor fixes current prices as a maximum price, and agrees to give the buyer advantage of all declines in market prices. Price terms in contracts sometimes include so-called escalator clauses, which provide for advances in the price under certain conditions which may concern the vendor's cost of material or of labor. It is essential that such escalator clauses be carefully worded so as to avoid any misunderstanding between the parties.

TERMS.—Terms as to f.o.b. point and cash discount should be plainly stated. The f.o.b. point is preferably on cars at the purchaser's freight station or siding, since this provision leaves title to goods in the vendor's hands and at the vendor's risk during transport. In instances where the contract is for delivery of goods at more than one plant, delivery f.o.b. point of origin is preferable, title to the goods then transferring to the purchaser. In some instances vendors refuse to accept hazards of ownership during transport, but are willing to allow the purchaser the transportation charges, the terms being f.o.b. shipping point with freight allowed.

TIME CLAUSES.—Time clauses are important in purchase contracts. Delivery may be agreed to be made within a certain period, on a certain date, or in accordance with purchaser's instructions. The most favorable kind of contract in this respect is one that calls for delivery "within period from .... to .... as called for by purchaser." The statement of the delivery agreement should be clear.

Time should be of essence in purchase contracts. A clear statement of the right to cancel and refuse deliveries, if not made on time, should be included in the contract. Every contract should contain a definite statement as to its termination, either by lapse of time or by action of parties. Many contracts are so loose in their conditions as to time of delivery as to have little effect, except that of a price agreement held open during the period for which the contract runs. Many purchasers favor this kind of contract, since it binds the vendor to responsibility, while placing no responsibility upon the purchaser. It is a mistake, however, to think of such limited price agreements as contracts of purchase.

Special conditions are sometimes necessary in purchase contracts for the protection of the purchaser's or vendor's interest. Such conditions should be stated specifically and not left to mutual understanding. Examples of such special conditions are given in the following paragraphs.

STATEMENTS OF OWNERSHIP.—Statements of ownership of special patterns, tools, fixtures, etc., required for the manufacture of certain products is an extremely important point to be definitely covered, whether in a contract or an order form. Custom varies widely as to ownership of such tools. In certain instances the purchaser of the goods pays for these facilities and they are his property, subject to removal by him at any time that he desires to place his orders elsewhere. Often, their cost is included in the price of the first order, and subsequent orders are filled at a lower price. A purchaser, in such a case, may regard himself as owner with the right of taking them away whenever he desires. It has been held, however, that special devices are not necessarily the property of the purchaser unless specific arrangements to this effect have been made at the time of the initial order. Where their number and cost are large, ownership by the vendor practically dictates placing all orders with him. Even were the purchaser willing to go to the expense of providing a second set, the time involved in their production might preclude this step.

In some cases special tools and fixtures may not be adapted to the equipment of another manufacturer. In other instances, while patterns, tools, etc., are the purchaser's property, he has no right to remove them from the vendor's possession. Such a contract may be of advantage to the purchaser, however, if it prevents the vendor from using them to make products for other customers.

Purchase contracts should cover, in considerable detail, the following points in regard to special equipment:

1. Ownership.
2. If title rests with vendor, whether or not purchaser has a right of purchase of this equipment.
3. Limiting use of special equipment to purchaser's product and forbidding their use on material manufactured for competitors.
4. Party who should bear expenses of maintenance and repairs of special patterns, tools, and fixtures.

INSPECTION AT VENDOR'S PLANT.—Inspection at the vendor's plant should be included in the purchase contract, if such inspection is contemplated. The vendor should agree, and the extent of inspection should be stated as specifically as is practical. Such equivocal expressions as "satisfactory quality," "reasonable inspection," etc., should be avoided. Definiteness in stating inspection standards and privileges with a clean-cut agreement as to whose decision shall be final, avoids many difficulties. Perhaps the most satisfactory form of agreement to cover inspection ties the inspection in with a definite printed specification identified beyond question in the contract.

GUARANTIES.—Guaranties are contract obligations of the vendor to furnish quality, quantity, or service. A guaranty adds nothing to a purchase contract unless it is a definite guaranty of a specific thing, not covered by the general contract. A guaranty of service for a fixed period after delivery, or against defect discovered within a fixed period, is a valuable protection to the purchaser in some cases.

PENALTY CLAUSES.—Penalty clauses in contracts obligate the vendor to make good any specified losses suffered because of his failure to meet the time obligations in the contract. The vendor may file a bond to guarantee performance of the contract, or the contract may contain a statement of the amount of payments which shall be accepted as liquidated damages in full settlement for defaulting on the contract. Such a clause is fair because it protects both vendor and purchaser.

BLANKET CONTRACTS.—Blanket contracts are useful in the case of companies operating several plants where there is a sufficient degree of localized purchasing authority, so that the purchasing departments of the several plants may order shipments against them. In such cases invoices are against the several plants and are paid by them. Such contracts are valuable in securing a sufficient volume of purchase for a price advantage, when the demand of any one plant is too limited to give that advantage.

Typical contract clauses are listed below:

It is agreed that we will issue from time to time a manufacturing schedule or will issue shipping instructions covering the quantity of material hereunder so as to provide a reasonably uniform rate of production.

It is agreed that you will invoice us as of .... for such material manufactured by you and for which we have not issued shipping instructions. It is understood that such manufacture shall not be in excess of the total quantity of material specified hereunder.

As to such material not manufactured as of .... we shall have the option, to be exercised within a period of .... days thereafter, either of canceling this contract as to such unmanufactured portion of said material, or of continuing this contract for a period not to exceed three months, in which latter event you agree to manufacture within this period the remaining quantity of the material not so manufactured. In the event that shipping instructions have not been issued for such material within the three months' period, you will, at the expiration of such three months, invoice us for such material. It is expressly understood that we reserve all of our rights to hold you liable for damages sustained as a result of your failure to perform any of the provisions of this contract, notwithstanding anything to the contrary herein contained.

It is agreed that all material invoiced to us and carried by you as our property will be properly stored by you and shipped as specified by our orders without further charges to us, provided such shipping instructions are given within a period of six months after the expiration date of this contract. It is understood that the storage of this material does not obligate you to pay for any insurance or taxes on the same.

It is agreed that upon request you will plainly mark such stock of material so invoiced as being our property and will execute and deliver a bill of sale in form acceptable to us together with satisfactory evidence that the material is free from all liens, charges, or encumbrances.

Delivery as ordered, bill as shipped, except as otherwise provided.

You agree to follow such routing instructions as may be furnished by our general traffic department.

It is understood that any of our houses or subsidiary or allied companies may place orders with you applying on this contract.

If shipping orders are issued for shipment during any period, in excess of the schedule as shown or such other schedules as we may issue, not to exceed the maximum covered by this contract, manufacture shall be increased, if possible, for such period so as to fully cover such shipping orders. Such increases in excess of the schedules as shown, however, shall not increase the maximum quantity of material hereunder.

It is agreed that we will issue from time to time a manufacturing schedule or will issue shipping instructions, covering the minimum quantity of material hereunder, so as to provide a reasonably uniform rate of production, and within thirty days prior to the expiration date hereof, we shall have the option of issuing an additional manufacturing schedule or shipping instructions covering the maximum quantity as above set forth.

By accepting this contract you hereby warrant the merchandise to be furnished hereunder will be in full conformity with the specifications, drawing, or sample, and agree that this warranty shall survive acceptance of the merchandise and that you will bear the cost of inspecting merchandise rejected.

By accepting this contract you hereby guarantee and agree that the merchandise to be furnished hereunder will not infringe any valid patent or trade-mark, and that you will, at your own expense, defend any and all actions or suits charging infringement and will save us, our customers, and those for whom we may act as agent in the purchase of said merchandise, harmless in case of any such infringement.

LEGAL ASPECTS OF CONTRACTS.—Legal aspects of purchase contracts demand close attention. In drawing up contracts which involve penalties and liquidated damages or any clauses of a complicated legal nature, legal advice should be sought. Important factors in the writing of contracts follow:

1. Only the matter which appears above the signature is binding.
2. Any additions or revisions in the original text of a contract should be initialed or signed by the parties to avoid any claim of alteration after signature.
3. All necessary provisions should be placed in the contract. It is not safe to depend on formal clauses printed at the bottom of the page or on its back. If they are used, a clause such as the following should be printed above the signature on the contract: "The clauses printed on the back (at the bottom) of this order are hereby made a part of this contract."

4. Printed matter in the body of the contract and above the signature is binding. Such printed matter, no matter how small the type, should be read carefully before signing.
5. The entire agreement between the parties should be expressed in the contract.
6. Every clause of the contract should be made definite to the point of making misunderstanding impossible.

STANDARD PURCHASE CONTRACT FORMS.—Standard purchase contract forms are adopted by some large manufacturers for the sake of assurance that their interests will be safeguarded without the necessity of legal advice on each purchase agreement. It is difficult, however, to make up a standard purchase contract which will cover all circumstances and be satisfactory to all vendors. Special clauses or insertions are required, therefore, when some unusual condition is included in a contract.

Purchasing Procedure

STEPS IN THE PROCEDURE.—The main steps in the procedure of procuring goods for industrial production, as stated by Davis, are listed below, together with the typical forms used at each step. On important items the actual issuing of the order is but one step in the procedure. The general plan of operation, sources of supply, period to be covered, and other significant factors should all be determined in advance.

1. Initiation of request in the form of a purchase requisition from department needing the goods—the purchase requisition to the purchasing department.
2. Determination of what and how much to buy.
3. Making a study of market conditions to find out .. the time is favorable to buy.
4. Determination of source of supply from which goods shall be purchased—catalogs, indexes, quotation and price records, and vendor records in the purchasing department.
5. Obtaining, by inquiry, quotation, or bid, a favorable price and selecting the specific vendor—quotations or bids, bid analysis sheets.
6. Entering into contractual relations with the vendor—the purchase order.
7. Securing performance by the vendor in delivering the goods on time —follow-up service.
8. Actually receiving the goods and delivering them to the storeroom or the department that requires them—receipt and inspection (in many cases not a function of the purchasing department).
9. Checking and completing the transaction—checking receiving report for quantity and quality factors, purchase contract for price, invoice for extensions, and adjustment of any discrepancies in quality, quantity, etc., vendor's invoice, and returns for credit and exchange.

ORIGIN OF PURCHASE REQUISITION.—The purchase requisition may be originated by the stores records supervisor, production control department, head of some operating department, the chief storeskeeper, plant or maintenance engineer, office manager, or other responsible person authorized to request that items which he needs be obtained from an outside vendor, if within the department's budget allot-

ment. Limitation of power to issue purchase requisitions is necessary, and a general procedure order should be set up by the management stating definitely which persons in the company are permitted to issue or sign purchase requisitions for the kinds of items they are allowed to obtain. Requisitions from all other persons must be turned back to be countersigned, if approved, by the proper authorized person, or canceled if not approved. It is likewise standard practice in well-run companies to require that all purchase requisitions be "edited," that is, reviewed to see first whether the items requested are carried in the storeroom, whether the request for some unusual items could not be satisfactorily filled by something carried in the storeroom, or whether something requested of a highly special nature which has to be purchased outside could not be replaced by some more standard item more readily obtainable and costing less than the article requested. The requisition also should be checked against the purchase budget, if such work is assigned to the purchasing department, to see that the item is within the current allotment for that class of materials, and within the current period's total budget allotment of the requisitioning department.

Form of Requisition.—The purchase requisition (see Fig. 9) will vary somewhat in form according to its point of origin and the accounting system in use. The form should contain the following essential information:

1. Name and accurate description of goods wanted, also stores symbol.
2. Quantity needed, and units of issue in which it should arrive, to save repacking upon receipt.
3. Date on which goods will be needed.
4. Account to which goods are to be charged.
5. Statement of need that justifies requisition. Executive or departmental approval may relieve the purchasing department of the responsibility for justification of the requisition, provided the executive order definitely releases the purchasing department of that responsibility on condition of proper approval.
6. Amount on hand and past or current rate or record of use.
7. Point of delivery within the plant to which the shipment should go, either after passing through receiving and inspection, or directly as in the case of such items as machinery which should be unloaded as close to point of use as possible.
8. Vendor's name, but in certain special cases only, as in repair parts for equipment. Selection of the vendor is ordinarily a purchase duty.
9. Authority for purchase, either by signature to requisition, or whatever approval by the superintendent, the stores department, etc., is required.
10. A space or form for use of the purchasing department in adding vendor's name, price, terms, routing, estimated weight, number of purchase order issued, and all other information necessary for typist in making out purchase order. Later, entry of delivery date promised by vendor.

In case of requisitions from the control department, production reference to the order or lot number of a production job is sufficient justification, and this information is sometimes conveyed by the account number to which goods are to be charged. In requisitions from the plant

engineer, office manager, etc., enough information should be included to enable the purchasing department to pass intelligently on questions of need and quantity.

The form of purchase requisition will vary with many factors. Two typical forms are shown in Figs. 9 and 10. Requisition forms should be of a size to fit standard files and preferably should be distinctive in color from other forms in the purchasing system.

Route of the Requisition.—The purchase requisition may go first to the purchase or quotation record desk on entering the purchasing department, to be compared with records of previous transactions for the same commodity. If the goods asked for by some department are carried in stores, the requisition can be returned to the requisitioning department with instructions to secure the items from stock. If the quantity wanted is in excess of previous requirements as indicated by the

PURCHASE REQUISITION

Dept. ....
Requisition No. ....
To Purchasing Agent: Date. ....
Please order the following: Requested by. ....
Ship to. .... Approved by. ....
.... Checked by. ....
Via. ..... F.O.B. ...... Terms. ...
Date Material Wanted. ....

Quantity	Description	Material on Hand	Average Consumption	Price

Special Instructions

Ordered from. .... Purchase Order No. ....
Date Ordered. .... Approved by. ....
Purpose. .... Checked by. ....
Charge to. ....

FIG. 9. Purchase Requisition
(The Purchase Requisition, N.A.P.A.)

record, the reason for such unusual requirements can be checked. If the quantity varies from a standard package or economical ordering quantity, the quantity can be adjusted. The purchase record or quotation card for the particular item may be attached to the purchase requisition, and both may be submitted for the buyer's consideration, since the purchase record will also show possible sources of supply, past experi-

REQUISITION
GULF 127

FROM ______________________ DATE ____________ 19___ REQ. NO. __________
DISTRICT DIVISION OR REFINERY

TO BE SHIPPED TO ______________________________

ON HAND	QUANTITY	MATERIAL	ITEM	PRICE	VIA	F O B	TO BE PURCHASED FROM OR TRANSFERRED FROM	ORDER NO	WHEN NEEDED	TO BE USED FOR
			1							
			2							
			3							
			4							
			14							
			15							
			16							
			17							
			18							
			19							
			20							

APPROVED BY __________ APPROVED BY __________ APPROVED BY __________ SIGNATURE OF PERSON MAKING REQUISITION __________

Fig. 10. Requisition for a Number of Items, Providing for Several Necessary Approvals

Fig. 11. Flow Chart of Purchasing Procedures in a Large Company
(Stuart F. Heinritz, "How the Bausch & Lomb Optical Company Buys," in How Industry Buys, Purchasing Magazine)

ence with these sources, price variations over a period, terms on previous orders for the goods, and all essential facts to make a complete picture of the transaction contemplated.

An alternative routing of purchase requisitions takes them first to the buyer's desk and then to the record desk only when the buyer feels that comparison with the record of previous transactions is desirable.

Fig. 11 is a flow chart showing the course of the purchase authorization (requisition) and other forms and procedures in the purchasing department.

REQUEST FOR QUOTATION.—The buyer must decide—once a purchase requisition has reached him and received his approval as to quantity, form, and propriety—with what vendor the order shall be placed. His primary interest is to secure, from a list of vendors in whom he has confidence as to quality of product and ability to make proper delivery, one who will give him the best or, at least, the right price. He may have price information available either in the form of catalogs and price lists submitted by some vendor, or in the general quotations already received.

INQUIRY FOR PRICES

THIS IS REQUEST FOR QUOTATION ON THE ITEMS ENUMERATED HEREIN

NO.________

DATE________

QUOTATIONS MUST BE IN BY________

THIS INQUIRY IMPLIES NO OBLIGATIONS ON THE PART OF THE BUYER

IF SUBSTITUTES ARE OFFERED MAKE FULL EXPLANATION

FOR SHIPMENT TO________ DATE SHIPMENT CAN BE MADE________

DELIVERY F.O.B.________ TO BE SHIPPED FROM________

TERMS: NET CASH________ DAYS________ %________ DAYS

KEEP ONE COPY FOR YOUR FILES RETURN ONE COPY WITH FULL INFORMATION

ITEM NO.	QUANTITY	ITEM AND SPECIFICATIONS	UNIT	LIST PRICE OF UNIT	DISCOUNT OFFERED	NET UNIT PRICE	ESTIMATED GROSS WT
		THIS IS NOT AN ORDER					

THE UNDERSIGNED OFFERS THE PRICES TERMS AND DELIVERY HEREIN SET FORTH

BY________ PURCHASING AGENT

BY________ SELLER'S SIGNATURE

FIG. 12. Inquiry for Prices

If he is not satisfied with his knowledge of the right price to be paid, or if there is any doubt as to which vendor will give the best price, he should issue a request for a quotation on the items covered by the purchase requisition (see Figs. 12 and 13). This request should be specific in describing the material, and in identifying it with the vendor's product, by catalog designation, when this is possible.

ALCOA ALCOA

PURCHASING DEPARTMENT
GULF BUILDING
To________ PITTSBURGH, PA.________

Gentlemen
Please quote itemized prices for materials listed below for shipment via ________

To ________

Refer to Requisition No. RALPH O. KEEFER,
Purchasing Agent

SUBSTITUTIONS, IF ANY, MUST BE CLEARLY SHOWN	LIST *	DISCOUNT	NET

Delivery Date Required Shipping Date Required Approx Shipping Weights

Quotation must be in our office on or before ________. Please state when shipment can be made.
Return one copy to GULF BUILDING, PITTSBURGH, PA

Offer No ________ Quotation Date ________
We offer to sell to you the above material at the price and terms specified hereon and upon the conditions printed on the back hereof and offer to make shipment within ________ days from receipt of order

TERMS OF SETTLEMENT
CASH DISCOUNT________ F. O. B.________
Unless otherwise specified we agree to accept your regular terms of settlement which are 2% for cash on the 20th of month for shipment made during the preceding month.

(Signed)________

THIS IS NOT AN ORDER

FIG. 13. Request for Quotation

Thomas D. Jolly, Vice President of Engineering and Purchasing of the Aluminum Co. of America, points out that every buying organization has its own preferred terms and conditions of purchase. He recommends that these be printed on the back of the request for quotation, and the clause shown in Fig. 13 printed on the front of the request above the space for seller's signature. Under these conditions the order becomes an acceptance of the offer, where otherwise the order may become a counter-offer. The identical conditions are printed on the back of the purchase order. This procedure saves much delay and misunderstanding.

Information on the Request.—The request for quotation should give the following information, essentially in the form in which it will appear later on a purchase order:

1. Quantity to be ordered.
2. Name and full specifications of material.
3. Point to which goods are to be delivered.
4. Delivery time which is to be allowed.
5. Date on which quotations will be considered.

It should ask for the following information:

1. Price.
2. F.o.b. point.
3. Terms of payment.
4. Delivery time.
5. Any special conditions or terms the vendor wishes to make. This point is often covered by a clause on the request for a quotation form which reads: "Except as stated specifically in your reply, your quotation will be considered as subject to the following conditions." All conditions of purchase desirable from the buyer's point of view are then tabulated.
6. Approximate shipping weight, provided this information is necessary. Often this question applies to purchases for export.

To Whom to Send Requests.—The question as to whom requests for quotation should be sent depends upon buyer and his records. The purchase or quotation record card should indicate any sources of supply that previous experience has shown to be unsatisfactory and why. It also should reveal past experience with vendors in regard to price, quality, delivery, and service. In the case of a new item of purchase, dependence must be placed on the buyer's knowledge of the vendor field, or on manufacturers' or dealers' registers, files of advertising matter, catalogs, etc.

Requests for quotations should be sent usually to not less than three, and not more than five, possible sources of supply, the companies selected being those giving the broadest possible price picture. In a plant situated in a small city about equidistant from two large cities, it would seem desirable to secure one quotation from each of the two large cities and one from a local source, especially in the case of goods purchasable from dealers, where variation of price might be expected in different geographical locations due to local trade conditions. On some goods it is well to send inquiries to both manufacturers and dealers, particularly on items which are being purchased from some dealer. If the buying company sells through dealers or jobbers, it would have an interest in purchasing from them. If not, it may find it advantageous to buy from whichever source—dealer or manufacturer—offers the best price in each individual case.

It is common practice to send requests for quotation in duplicate, one copy to be filled in and returned as a quotation by the vendor. The advantages of reply forms for quotations are:

1. Uniformity of quotations for tabulation and filing.
2. Assurance that all points will be covered in quotation.
3. Certainty that buyer's terms of purchase will be either accepted or specifically negatived.
4. Economy in quotation contact.

One method of determining when and to what extent quotations should be requested in advance of placing an order is to establish a dollar amount as the dividing line. If the order exceeds this amount, quotations must be received and the price shown on the purchase order sent to the vendor. Below this amount no quotations need be secured. Such a procedure allows small orders to go out unpriced.

Follow-Up on Requests.—How far requests for quotations should be followed up depends on how badly quotation information is needed. Some companies make it imperative that all quotations be submitted on or before a given date, and rule out all not received by the time the closing of bids arrives. Often it is desirable to secure all quotations requested before orders are awarded. For this purpose the quotation record card or analysis sheet may be used as the basis of a follow-up system, showing at all times what requests for quotations have been sent out and what quotations received. This card may be placed in a tickler file to bring up unanswered requests in time for follow-up, or it may be keyed by a marker as to follow-up date and placed in a visible index or other card record file.

Use of the Quotation Record Card.—The quotation record card is also medium for tabulating and comparing quotations and deciding from whom the goods shall be ordered. Quotations should be tabulated with extreme care to note all deviations from specifications or essential items, and to show in columnar form the comparison of prices, deliveries, and terms, all reduced to the same basis. Fig. 14 shows a typical quotation record card or analysis sheet. In some cases it is simpler to use the file copy of the inquiry instead of a quotation record card or analysis sheet. The file copy is then used for follow-up purposes, where desirable, and provision may be made on the file copy for tabulation of quotations when received. This system has the advantage of placing before the buyer, on one document, an exact copy of his request for quotation, a record of all concerns to whom the request was sent, and a tabulation of the quotations received.

SELECTING THE VENDOR.—From the data on questions thus assembled and analyzed on the quotation record card, or a corresponding form on the copy of the request for quotation, the buyer selects the vendor with whom he wishes to place the purchase order. Frequently the purchase requisition form is used as the basis of writing the order. This form, after the buyer adds to it the necessary information as to source of supply, price, etc., passes to the typist who makes out the purchase order. All information should be in such clear form that the typist need have no questions or misunderstanding regarding the order. The requisition is given to the buyer with the purchase order for comparison and checking, after which the latter is signed and mailed. The purchase requisition is then marked with the purchase order number for

QUOTATION ANALYSIS SHEET

REASON FOR SELECTION OF VENDOR (If not Low Bidder)

*SPECIFICATIONS ☐ DELIVERY ☐ ONLY SOURCE ☐

*SPECIFICATIONS APPROVED BY ____________

OTHER REASON OR REMARKS

VENDOR AND DATE OF BID	1		2		3		4		5		6		7		8
F O B. F A S.															
TERMS															
WEIGHT															
BEST DELIV'Y															
ITEM		✓		✓		✓		✓		✓		✓		✓	
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															
TOTAL															

(✓) Check Column Designating Low Bidder Per Item

BUYER'S SIGNATURE ____________

FIG. 14. Quotation Record Card or Analysis Sheet

reference purposes, and is filed under department of origin. If in duplicate, the copy is returned to the department which originated it, with purchase order number and other needed information added. Often, however, a copy of the purchase order, perhaps with certain information blanked out, is sent to the requisitioner to indicate that his request is being filled.

THE PURCHASE ORDER.—The purchase order is the vendor's authority to ship and charge for the goods specified, and is the buyer's commitment to the vendor for the value of the goods ordered. It is an integral part of the sales agreement and establishes a contractual relationship immediately upon issuance, when it is an acceptance of a previous quotation or offer. Otherwise it is an offer to negotiate such a contractual relationship which is completed by its acknowledgment or acceptance by the vendor. It is the most important of purchasing forms, and its provisions should be planned with care and continually considered as to desirable revision. A typical purchase order form is shown in Figs. 15a and 15b and the simplified practice recommendation nationally adopted for zoning purchase orders is shown in Fig. 16.

The purchase order should cover definitely and precisely the essential elements of purchase to be made, in a manner which will render future misunderstandings impossible and minimize the necessity of correspondence. It should be worded as far as possible exactly like the request for quotation, if one was sent out, and should include the following data.

Number.—A purchase order number which will identify the transaction in future correspondence will be used by the vendor in shipping and billing the goods, and will enable the contract to be recorded and filed for future reference. The vendor should be instructed to put the purchase order number on all packages, and on all his invoices so that they may be identified with the purchase order, for comparison and checking purposes. Since the receiving department will have a copy or a record of the order, including its number, all receipts of goods against it will be identified.

Quantity Ordered.—Quantity of goods ordered is expressed in the units proper for the commodity. A clause should appear in the order form, limiting the vendor's right to overship or undership the order. A few illustrations of clauses of this nature follow:

The quantity of material ordered must not be changed without permission of buyer.

Quantity of material must not be exceeded without buyer's permission in writing being first obtained.

The right is reserved to return excess shipments at shipper's expense.

Quantities received by us in excess of quantities specified herein may be returned, at our option, at shipper's expense.

In expression of units the Aluminum Co. of America guards against misunderstandings by the following instructions to its buyers:

1. Never use the abbreviation CWT but write one hundred pounds or the figures 100 lb.
2. Never specify tons without stating kind—net ton, gross ton, or metric ton.
3. Never write dimensions using symbols for feet and inches; write 8 feet 3 inches or 8 feet 0 inches instead of 8′-3″ or 8′.

GULF OIL CORPORATION
GENERAL PURCHASING DEPT.
GULF BUILDING, PITTSBURGH, PA.
(FOR ACCOUNT OF MENE GRANDE OIL COMPANY, C.A.)

GULF

DATE ____________

ORDER NO.

REQ. NO.

IMPORTANT
SHOW ORDER AND REQUISITION NUMBERS WHEN BILLING AND CORRESPONDING ON ABOVE ORDER.

SHIP TO: MENE GRANDE OIL COMPANY, C.A., CARE OF GULF OIL CORP.

STRICTLY IN ACCORDANCE WITH ATTACHED SHIPPING INSTRUCTIONS.

THE MERIT OF YOUR PRODUCTS HAS CONTRIBUTED TO YOUR RECEIVING THIS ORDER. LIKEWISE, MAY THE MERIT OF GULF PRODUCTS HAVE YOUR CONSIDERATION

VENEZUELAN CUSTOMS LAW DOES NOT PERMIT ANY OVER-SHIPMENT OF THIS ORDER. CONSEQUENTLY, ANY SHIPMENT WHICH EXCEEDS OUR SPECIFICATIONS WILL BE RETURNED AT YOUR EXPENSE.

CHARGE: MENE GRANDE OIL CO. C.A. CARE OF GULF OIL CORPORATION SENDING INVOICES, PACKING LIST AND BILL OF LADING (OR EXPRESS RECEIPT) IN ACCORDANCE WITH ATTACHED SHIPPING INSTRUCTION.
ON ORIGINAL AND ALL COPIES OF INVOICE SHOW COUNTRY OF ORIGIN FOR MATERIAL SPECIFIED.
ULTIMATE DESTINATION OF MATERIAL — VENEZUELA, SOUTH AMERICA.
INSTRUCTIONS AND CONDITIONS SET FORTH ON THE REVERSE SIDE OF THIS ORDER ARE INCORPORATED INTO AND MADE A PART HEREOF.

PLEASE FILL OUT ATTACHED ACKNOWLEDGMENT SHEET AND RETURN IMMEDIATELY.

D. G. CLARK
DIRECTOR OF PURCHASES

BY ____________

Fig. 15a. Purchase Order (*face*)

CONDITIONS UPON WHICH THIS ORDER IS ACCEPTED

1 F O B POINT AND CASH DISCOUNT TERMS MUST BE SHOWN ON ALL INVOICES.

2 TRANSPORTATION MUST BE PREPAID ON ALL SHIPMENTS TO WHICH A DELIVERED PRICE APPLIES.

3 CHARGES FOR PREPAID TRANSPORTATION MUST BE SUBSTANTIATED BY ATTACHING TO THE INVOICE ORIGINAL TRANSPORTATION BILLS RECEIPTED BY THE CARRIER

4. THIS ORDER MAY NOT BE FILLED AT PRICES HIGHER THAN THOSE LAST CHARGED OR QUOTED FOR THE SAME MATERIAL, WITHOUT NOTIFICATION AND ACCEPTANCE OF THE ADVANCED PRICES

5. NO CHARGES FOR PACKING, PACKAGE OR DRAYAGE WILL BE ACCEPTED, EXCEPT ON EXPRESS AGREEMENT TO SUCH CHARGES.

6 FAILURE TO COMPLY WITH SPECIFICATIONS, TERMS AND CONDITIONS OF THIS ORDER, OR TO DELIVER MATERIAL IN ACCORDANCE WITH THE SELLER'S PROMISE SHALL BE GROUNDS FOR CANCELLATION BY THE PURCHASER WITHOUT PENALTY.

7 DRAFTS AGAINST THE PURCHASER WILL NOT BE HONORED, NOR C O D. SHIPMENTS ACCEPTED, EXCEPT BY EXPRESS AGREEMENT TO THAT EFFECT.

8 SHIPMENTS BY PARCEL POST OR COMMERCIAL STEAMSHIP LINES SHOULD BE INSURED AT FULL VALUE AND EXPRESS SHIPMENTS SHOULD BE MADE ON THE BASIS OF DECLARATION OF FULL VALUE, EXCEPT WHEN OTHERWISE AGREED.

9 STRIKES FIRES, ACCIDENTS, OR OTHER CAUSES BEYOND THE CONTROL OF THE PURCHASER, WHICH SHALL AFFECT THE PURCHASER'S ABILITY TO RECEIVE AND USE THE MATERIAL ORDERED, SHALL CONSTITUTE VALID GROUND FOR SUSPENSION OF SHIPMENT UPON THIS ORDER, UPON NOTIFICATION TO THE SELLER BY TELEGRAM OR LETTER AND WITHOUT PENALTY TO THE PURCHASER EXCEPT THAT CANCELLATION FOR SUCH CAUSES MAY NOT BE MADE WITHOUT REIMBURSEMENT TO THE SELLER FOR EXPENDITURES ACTUALLY MADE FOR LABOR AND MATERIALS UPON THE AUTHORITY OF THIS ORDER.

10 THE SELLER AGREES TO INDEMNIFY AND SAVE HARMLESS THE PURCHASER FROM ALL CLAIMS ARISING OUT OF ANY INFRINGEMENT OF PATENTS IN THE PURCHASE OR USE OF THE GOODS COVERED BY THIS ORDER, AND TO DEFEND AT THE SELLER'S EXPENSE ANY AND ALL ACTIONS BASED ON SUCH CLAIMS OF PATENT INFRINGEMENT

11 THE SELLER WARRANTS THAT NO LAW, REGULATION OR ORDINANCE OF THE UNITED STATES, OR ANY STATE, OR ANY GOVERNMENTAL AUTHORITY OR AGENCY HAS BEEN VIOLATED IN THE MANUFACTURE, PROCUREMENT, OR SALE OF ANY GOODS FURNISHED ON THIS ORDER.

12 THE SELLER AGREES THAT THE RELATIONSHIP ESTABLISHED BY THIS ORDER CONSTITUTES HIM AN INDEPENDENT CONTRACTOR, AND THAT NO TAX, ASSESSMENT OR LEGAL LIABILITY OF THE SELLER, OR OF HIS AGENTS OR EMPLOYEES BECOMES, BY REASON OF THIS ORDER, AN OBLIGATION OF THE PURCHASER

13 IN CASE OF ENTRY BY THE SELLER, OR OF ANY OF SELLER'S AGENTS OR EMPLOYEES, UPON THE PROPERTY OR PREMISES OF THE PURCHASER, FOR THE PURPOSE OF CONSTRUCTION ERECTION, INSPECTION OR DELIVERY UNDER THIS ORDER, THE SELLER AGREES TO PROVIDE ALL NECESSARY AND SUFFICIENT SAFEGUARDS AND TO TAKE ALL PROPER PRECAUTIONS, AGAINST THE OCCURRENCE OF ACCIDENTS, INJURIES OR DAMAGES TO ANY PERSONS OR PROPERTY AND TO BE RESPONSIBLE FOR AND TO INDEMNIFY AND SAVE HARMLESS THE PURCHASER FROM ALL LOSS OR DAMAGE AND ANY OR ALL CLAIMS ARISING BY REASON OF ACCIDENTS, INJURIES, OR DAMAGE TO ANY PERSONS OR PROPERTY IN CONNECTION WITH SUCH WORK, EXCEPT SUCH AS MAY BE THE SOLE AND DIRECT RESULT OF NEGLIGENCE ON THE PART OF THE PURCHASER, AND FROM ALL FINES, PENALTIES OR LOSS INCURRED BY REASON OF THE VIOLATION OF ANY LAW, REGULATION, OR ORDINANCE; AND FURTHER AGREES TO DEFEND AT THE SELLER S EXPENSE, ANY AND ALL SUITS OR ACTIONS CIVIL OR CRIMINAL ARISING OUT OF SUCH CLAIMS OR MATTERS AND FURTHER AGREES TO PROCURE AND CARRY SUCH INSURANCE OF EMPLOYEES AS MAY BE REQUIRED BY ANY WORKMEN'S COMPENSATION ACT OR OTHER LAW, REGULATION, OR ORDINANCE, WHICH MAY APPLY IN THE PREMISES

14 IT IS AGREED BY THE SELLER THAT ANY RIGHT, CAUSE OF ACTION, OR REMEDY UNDER THE WARRANTIES OR UNDERTAKINGS ASSUMED OR IMPOSED UPON THE SELLER UNDER THIS ORDER SHALL EXTEND WITHOUT EXCEPTION TO ANY COMPANY AFFILIATED WITH THE PURCHASER OR UPON WHOSE BEHALF THIS ORDER IS ISSUED BY THE PURCHASER, AS THE INTEREST OF SUCH COMPANY SHALL APPEAR.

Fig. 15b. Conditions upon Which Order Is Accepted (*reverse of Fig. 15a*)

Description.—Description of goods ordered should be specific and, wherever possible, should state the basis and means by which quality is to be checked. Existing standards of quality and standard specifications are the most satisfactory for this purpose. Any unusual test, inspection, etc., to which goods are to be subjected should be stated. Material specifications as to quality should be fortified by inserting in the purchase order form a clause stating the rights as to rejection and return which purchaser reserves. Specimen clauses of this kind are:

All material furnished must be as specified and will be subject to inspection and approval of buyer after delivery. The right is reserved to reject and return at the risk and expense of the supplier such portion of any shipment as may be defective or fail to comply with specifications, without invalidating the remainder of the order. If rejected it will be held for disposition at expense of and risk of the seller.

All material and supplies furnished on this order will be subject to inspection before acceptance. If rejected, they will be held subject to the order of the shippers with accrued charges.

Goods subject to our inspection on arrival, notwithstanding prior payment to obtain cash discount.

Goods rejected on account of inferior quality or workmanship will be returned to you with charges for transportation both ways, plus labor, reloading, trucking, etc., and are not to be replaced except upon the receipt of written instructions from us.

Delivery and Shipping Instructions.—Delivery specification may be stated either as a date on which goods are to be shipped, or as a date on which goods are to arrive at the buyer's plant. The latter date is preferable because it can be taken directly from the purchase requisition without computation of time allowed for transit, and also because it shifts to the vendor the responsibility for transportation delays. A specific date should be stated, and expressions such as "Urgent," "Rush," "Prompt Shipment," "At Once," etc., should be avoided.

Delivery specifications may be buttressed by a clause in the purchase order stating the buyer's rights as to cancellation for default in time of delivery:

Buyer reserves the right to cancel this order or any portion of same if delivery is not made when specified, time being of the essence of this order, and to charge seller for any loss entailed.

Failure of shipper for any reason to fulfill delivery as promised will be considered sufficient cause to cancel this order.

Delivery must be made within the time specified on order. If material is not delivered within such specified time, buyer reserves the right to purchase elsewhere and charge seller with any loss incurred as a result thereof, or, at buyer's option, to cancel the order or any part thereof.

Shipping instructions include a statement of the point at which goods are to be delivered, routings, instructions as to packing material, and designation of method of shipping—parcel post, express, freight, etc. Many firms state in their orders: "Ship cheapest way unless otherwise specified," and reserve the right to charge back transportation charges in excess of the cheapest rate for shipment. A clause in the purchase order form may protect the buyer from charges which he is unwilling

to bear in connection with packing and shipping. Sample clauses of this nature are:

No charge allowed for packing or cartage unless designated on order.

Packing or cartage will not be included in the invoice price unless agreed upon in writing.

No charge allowed for packing or cartage.

All containers, drums, carboys, etc., to be returned, must be shipped on a no-charge or consignment basis. We will pay for only such containers as we do not return in a reasonable time.

Billing and Terms.—Billing instructions cover number of copies of invoice required, information desired on invoices, how invoices should be marked, to what point they should be mailed, etc. A typical provision is: "Invoice in duplicate and mail with shipping papers the day shipment is made." Billing instructions are usually uniform for all orders and may be included in the printed part of the purchase order form.

A definite statement of the f.o.b. point avoids misunderstanding. It is generally stated in connection with the price, if the price is placed in the purchase order.

Terms as to payment, including cash discount terms, are usually at the option of the vendor. They are stated in connection with quoted prices mentioned in the purchase order, but otherwise omitted. Understanding as to cash discounts should be established by correspondence with vendor firms and recorded in a file for checking invoices. Special terms as to payment by trade acceptance or draft should be stated in the purchase order in accordance with the agreement. Many companies include in their purchase order forms a statement protecting against drafts without specific agreement. Typical clauses of this nature are:

No drafts for purchases made will be honored unless by agreement.

No drafts for purchases made by this company will be honored.

Prices.—Prices should be stated in the purchase order, if the order is based on a quotation or an agreement as to price, together with a reference to quotation or agreement. Some vendors price all orders as received. This practice has the advantage of certainty of cost prior to billing. It has the disadvantages of added clerical expense for pricing, and the tendency of the vendor's billing clerks to follow the price in the order and not give the advantage of declines which might not be known to the buyer.

Stock clauses in the purchase order form are used to afford the buyer price protection. Typical examples are:

If price is omitted on order, it is agreed that seller's price will be the lowest prevailing market price.

This order must not be filled at prices higher than those above given or last quoted.

If price is not stated on this order, material must not be billed at a price higher than paid, without notice to buyer and its acceptance thereof.

If price is not shown on the original order sheet, it must be inserted by seller on the attached acknowledgment to be returned to buyer.

It is understood and agreed that seller will not charge, without buyer's consent, a higher price for the goods called for by this order than was last quoted or charged to this office.

Miscellaneous Clauses.—Miscellaneous clauses and conditions will vary with trade conditions or customs, nature of goods, and many other factors. Patent infringement is often subject of a clause such as follows:

Seller shall indemnify and save harmless the buyer and/or its vendees from and against all cost, expenses, and damages arising out of any infringement or claim of infringement of any patent or patents, in the use of articles or equipment furnished hereunder.

As a part of the consideration hereof, it is expressly agreed that the seller will indemnify and hold harmless the buyer, from any loss, damage, or injury arising out of a claim or suit for alleged infringement of patents, relating to the property described herein, and will assume the defense of any and all such suits, and will pay all costs and expenses incidental thereof.

It is agreed that goods ordered shall comply with all federal laws relative thereto, and that seller will defend and save harmless this company from loss, cost, or damage by reason of actual or alleged infringements of letters patent concerning same.

Other typical clauses on various conditions are:

The material on this order must be furnished only by the person or firm to whom the order is addressed unless otherwise authorized by the purchasing agent.

Seller agrees that no part of this order shall be sublet without purchaser's approval.

This order is confidential between the purchaser and the seller, and it is agreed by the seller that none of the details connected therewith shall be published or disclosed to any third party without purchaser's written permission.

When the cost of tools involved in the manufacture of parts covered by this order is included in the price per unit, tools become the property of this company upon the completion of our orders.

Any controversy or claim arising out of or relating to this contract or the breach thereof, shall be settled by arbitration, in accordance with the rules, then obtaining, of the American Arbitration Association, and judgment upon the award rendered may be entered in the highest court of the forum, state or federal, having jurisdiction.

It is agreed that the waiver or acceptance by us of any breach on seller's part of any of the terms of this order shall not operate to relieve seller of responsibility hereunder for any prior or subsequent breach.

It is impracticable to list or illustrate all special conditions which may require mention in a purchase order. Child labor laws, federal food and drugs act and revenue acts, and other statutes may require provisions in particular cases. In addition, there may be clauses covering responsibility for patterns, special causes for cancellation, penalties for default, etc., and other requirements. Clauses which are general and apply to all purchase orders of the company will be made part of the printed purchase order form. Special conditions particular only to the order in question must be typed in.

Many clauses have recently been developed as a result of state sales and use taxes, federal social security tax provisions, and federal and state wage and hour laws, etc. Ordinarily, it is sufficient to include a general provision that "nothing in the purchase order shall vary the legal responsibilities of either vendor or purchaser under federal or state laws." It is generally true that any attempt to insert clauses which shift such liability is nugatory.

Acceptance by the Vendor.—Acceptance or acknowledgment of the order must be made by the vendor to bind the agreement unless the purchase order is itself acceptance of a quotation or offer. It is desirable to insert, as a stock clause in the purchase order form, a provision requiring acknowledgment or acceptance by the vendor. Typical provisions are these:

Shipment of any part of this order constitutes acceptance of all its conditions without reservation. (This company used an acknowledgment form attached to the purchase order.)

Acknowledge this order promptly, giving date of shipment. (No means of acknowledgment furnished.)

Acknowledgment of this order must be made on acceptance copy attached and returned to us promptly. No other form will be accepted.

Mail this company's acknowledgment form of this order promptly and fill in complete, as we require this information for our records. We must have definite delivery date . . . "soon as possible" will not do. If delivery date is not satisfactory we reserve the right to cancel.

Acknowledgment of this order must be made in writing by return mail. Seller's failure to acknowledge may be considered an acceptance by the buyer.

In cases where previous quotations have not been obtained due to time conditions, or to the fact that only one vendor can furnish the material, the acknowledgment may be made the means of establishing a quoted price for the purchase records. A typical clause of this sort is:

In acknowledging this order it is essential that seller furnish complete quotation, including f.o.b. terms, cash discount terms, and approximate shipping weights, as well as its promise as to the time of delivery.

Other Data.—Accounting information given on the purchase requisition tells the purchasing department the account or job number to which the purchase is to be charged. This information need not go to the vendor. It should be typed into the purchase order, however, so that it will appear on duplicate, triplicate, etc., copies which are used internally for receiving and charging material.

Date, signature, vendor's name, etc., obviously are essential features of the purchase order. It is unnecessary to discuss them beyond stating that the signature should show the company name, and the name and position of the purchasing agent or officer authorizing the purchase. Some companies use rubber stamps for the signature of the purchasing agent, but the best practice is that each order should be signed by him or, if he does not sign personally, with his name and "By ....," inserting the name of the person actually signing.

Form and Number of Copies.—A specific form of purchase order is advisable as long as it is readily understood, economically handled by

vendor, and suited to the requirements of the purchaser's accounting system. It is highly advantageous, however, to use the standard purchase order form developed by the National Association of Purchasing Agents, and adopted as a Simplified Practice Recommendation by the Division of Simplified Practice, National Bureau of Standards, and in wide use. Advantages of use are:

1. Fewer misunderstandings and clerical errors.
2. Lower printing costs.
3. Economical use of standard paper stock.
4. Economy in filing due to standard size.
5. Economy in typing and recording.

The form is standard as to zones where data are located (see Fig. 16). Details of entry differ according to the needs of each company. Fig. 15a conforms to this standard. The number of copies of the purchase order to be made will vary with the requirements of the accounting system. A typical set-up uses six copies:

No.
1. Vendor's copy, mailed to vendor.
2. File copy, posted to purchase record card and filed under vendor's name.
3. Receiving copy, sent to receiving department.
4. Receiving ticket, sent to receiving department.
5. Receiving ticket, sent to receiving department.
6. Follow-up copy, goes to follow-up clerk, is filed in tickler file, and used to assure delivery of the goods when needed.

See Fig. 11 for distribution and use of copies of the purchase order under this set-up. Another typical set-up calls for eight copies distributed thus:

No.
1. Vendor's copy.
2. Acknowledgment forms; to be filled in by vendor and returned.
3. File copy for purchasing department, used for record purposes and for checking of invoice.
4. Follow-up copy.
5. Accounting department copy.
6. Receiving department copy.
7. Inspection department copy.
8. Requisitioner's copy.

FOLLOW-UP OF PURCHASE ORDER.—The importance of follow-up is obvious, since maintenance of uninterrupted production schedules depends primarily on receipt of material on time. Every order should bear a date for delivery and the duty of the follow-up service is to have that date kept, or to learn of unavoidable delays in time to take steps to prevent crippling the plant for lack of materials. It is the task of the follow-up section to:

1. Secure an acknowledgment or acceptance of order.
2. Secure a promise of delivery consistent with requirements.
3. Check with vendor on progress of filling the order, several times if the order is highly important.
4. See finally that the delivery promise is kept.

Some companies send the vendor two copies of the order, one of which is an acknowledgment form for signature and return. Another

National Standard Zone System for Purchase Order and Inquiry Forms

Zone 2
For name, address, etc. of buyer

Zone 1
For all necessary instructions of buyer and seller, in upper right-hand corner, convenient for reference in loose file or binder
(Includes order numbers, etc.)

Zone 3
For name and address of seller to whom purchase order is to be mailed

Zone 4
For shipping instructions

Zone 5
For general conditions of purchase

Zone 6
For listing materials ordered

Standard Zone System for Purchase Order and Inquiry Forms

The Zone System will, to all intents and purposes, serve as a Standard Purchase Order or Inquiry Form, in that each item of information will always be found in a definite place. Relative sizes of zones may be varied to suit needs of user.

The upper part of Zones 1 and 2 may contain information not necessary for the seller but of value as a record for the buyer, and may be detachable by perforation on the original copy.

Orders and inquiries should be on sheets 8½ inches wide, and either 7, 11, or 14 inches long.

Zone 7

Signature of Buyer

Fig. 16. Standard Arrangement of Purchase Order

common practice is to print a perforated acknowledgment slip on the purchase order, to be torn off, filled in, signed, and returned to the purchaser. It is good practice to demand acknowledgment by return mail as a condition of the order. If acknowledgment is not received after a reasonable lapse of time for exchange of mail, the follow-up section should write requesting acknowledgment. Form letters may be used for this purpose, or form postcards.

After acknowledgment is secured with a statement of delivery date, the follow-up section, if the order is important or special, will make later

checks on the vendor by form letters, postcards, or in urgent cases by telephone or telegraph. Reply forms are often included with requests from the follow-up section as a means of insuring a reply with the exact information requested. Fig. 17 shows a typical follow-up form.

When a broken delivery promise endangers shop schedules, emergency action should be taken through the purchasing agent or a buyer. Follow-up is based on a carbon copy of the order, with proper headings

PURCHASING DEPARTMENT

THE GOODYEAR TIRE & RUBBER COMPANY

AKRON, OHIO

Date ____________

WE ARE TRYING TO CONSERVE YOUR TIME AS WELL AS OURS BY USING THIS FORM. IT IS SENT IN DUPLICATE TO ENABLE YOU TO USE ONE COPY FOR A REPLY AND KEEP THE OTHER FOR YOUR FILES.

This is an IMPORTANT REQUEST for INFORMATION

Concerning Our Order No. ____________ Dated ____________, Please Answer Items Checked

SHIPMENTS			INVOICES		
	CK.	REPLY		CK.	REPLY
1 When will you ship?			11 Please mail invoices today.		
2 In what quantity will you ship?			12 Invoice is requested in {Duplicate / Triplicate}		
3 Did you ship on date shown by order? How?			13 Please mail Bill of Lading {Original / Duplicate}		
4 Can you advance shipping date promised?			14 Please mail Freight Bill		
5 Why did you not ship as promised?			15 Please send Certified Weight Sheet		
6 Please make your delivery promise more specific.			16		
7 Please start tracer on shipment made			17		
8 Release shipments as shown under remarks.			18		
9 When will remainder of order be shipped?			19		
10			20		

REMARKS

IN SELECTING OUR SOURCES OF SUPPLY WE GIVE CONSIDERATION TO THE RESPONSE GIVEN TO THE FOLLOWING REQUESTS:

1. THAT YOU WILL ENDEAVOR TO KEEP YOUR DELIVERY PROMISE.

2. THAT YOU WILL NOTIFY US OF ANY UNAVOIDABLE DELAY AS SOON AS YOU ENCOUTER IT.

3. THAT YOU WILL INVOICE PROMPTLY.

The Goodyear Tire & Rubber Company

By ____________

Fig. 17. Follow-up of Purchase Order

for notation of delivery information, etc. Follow-up copies should be filed in a tickler file under dated headings, which will bring each order up for review as to delivery conditions in ample time to allow for action. If the tickler file is to be divided among two or more clerks, it should be divided between local and out-of-town vendors rather than by commodities, or alphabetically. Division on the basis suggested allows the employment of clerks adapted to telephone communications for local accounts and those skilled as correspondents for out-of-town connections. In very large buying organizations, where volume of purchase demands several subdivisions of the follow-up task, it is wise to vary the rule laid down above and divide follow-up file on the basis of commodities, making each follow-up division subordinate to the particular buyer. An alternative practice is to file follow-up copies of orders numerically, or even alphabetically by vendors. In such cases, however, it is essential that there be a routine under which a numerical section of the orders or an alphabetical section shall be covered regularly, or some keying system provided to accomplish the same purpose, namely, periodic review of all orders for delivery purposes.

Self-Signaling Follow-Up Folders.—Special universal-type follow-up folders—used also in a follow-up system to get in bids—for letter-sized forms now come with transparent transloid guides across the top to hold the title inserts and movable transparent colored signals (Remington-Rand). To the right of the title insert space is a section divided by months, January to December, across which a red signal may be moved to indicate the month of follow-up. To the far right across the remainder of the top are the dates 1 to 31, over which a green signal can be moved to show the day of follow-up. Copies or memos of purchase orders are put in the folders, which are keyed by the signals for month and day of follow-up and may be filed in order of such date. Each day, inspection of the signals locates the folders holding purchase orders to be followed up on that day. The results of the follow-up are then noted on the respective forms, which may be resignaled and refiled for later follow-up if necessary. Such a system avoids the necessity for having a large folder file covering every date in the year. Only sufficient folders are required to cover the period over which, at any one time, follow-up of current purchase orders may extend.

Another way to use the file is to put a single purchase order in each folder and signal the folder. Under this plan, the purchase orders can be filed in numerical sequence, or alphabetically by vendor, or according to classes of commodities, or as urgent and routine, according to whatever plan the user chooses. Checking down the month-signals and across to the date-signals, or vice versa, locates the folders containing the orders to follow up each respective day. This method takes longer for picking out the daily follow-ups but eliminates a cross-reference file.

RECEIVING.—Duties of the receiving department include:

1. Checking incoming shipments to see whether items and quantities conform to order.
2. Recording receipt.
3. Taking necessary steps to insure inspection or testing when required.
4. Notifying department, or storeroom, of receipt of shipment and its amount and condition.

5. Informing purchasing agent or buyer of all facts which require an adjustment with vendor, whether for overshipment, shortage, or defective material.
6. Delivering material to proper point in plant for storage or use.

The receiving department should receive a copy of the purchase order or purchase requisition with which to check incoming shipments for proper goods, quantity, quality, and all other essentials. Any variation from shipping instructions on the order should be noted. It is good practice to omit showing quantity ordered on all copies of orders sent to the receiving department, so that this department must actually count or weigh goods without knowledge of amount ordered.

The record made of the goods received should be in a form suitable for checking against the vendor's invoice and against bills for transportation charges. It is usually given in the form of a **receiving report.** Such a record should show:

1. Purchase order number.
2. Date of receipt.
3. Vendor's name and address.
4. Kind of goods.
5. Quantity received.
6. Condition when received (whether damaged, etc.).
7. Units in which the goods came in (pieces, quantity per box or package, etc.).
8. Type of container.
9. Any necessary identifying marks on shipment.
10. Complete or partial shipment.
11. Vendor's invoice number.
12. Medium of transportation.
13. Transportation charges.
14. By whom received.
15. To whom delivered.

Four copies of the receiving report may be made, one copy remaining as a receiving record, one going to the purchasing department for comparison with the order, and one to the department to which the shipment is sent (usually the storeroom), and perhaps one to the accounting department as a voucher for invoices. Sometimes the record may be made

RECEIVING VOUCHER

THE FOLLOWING MATERIAL HAS ARRIVED AT THE RECEIVING DEPT. Date________19

SHIPPED BY FROM PUR. ORDER NO.

Packages No.	Packages Kind	Quantity	DESCRIPTION	Weight	Chargeable to

Delivered	Carting Co.	Pur. Agent's Bill No.	Received by:
Via	R.R. or Exp Co.	Date of Invoice	Count and Weight Checked by
Car No.	Initial	Checker's Report No	Received for Division Stores by:
Pro. No.	Weight	Condition of Shipment Upon Arrival·	Checked Against Invoice by:
Rate	Frt. or Exp. Ch'g's $		

FIG. 18. Receiving Voucher

on copies of the purchase order, typed as a measure of economy at the same time as other copies of the order. Such receiving copies of the order are headed and spaced to allow entering of receiving information.

The receiving department's copy of the purchase order must show the point where the goods are to be delivered. A receipt should be secured from this department. If receiving tickets have been sent with the copy of the purchase order to the receiving department, this department will

RECEIVING TICKET DATE OF RECEIPT
4 40596
ON RECEIPT OF GOODS FILL IN QUANTITY AND RETURN TO PURCHASING DEPARTMENT

FOREMAN

RECEIVING TICKET DATE OF RECEIPT
3
TIME NO O. K.
ORDER NO. 40596
BILL POSTED
DATE OF BILL
MONTHLY CHECKING
FREIGHT & EXP CH'G'S
AM T OF BILL

IMPORTANT:
ON RECEIPT OF GOODS FOREMAN MUST FILL IN QUANTITY AND SEND TICKET TO TIMEKEEPER'S OFFICE WITHIN 24 HOURS.

VIA

QUANTITY RECEIVED

DATE PUT INTO STOCK
DATE SENT TO OFFICE
ENTERED ON STOCK CARDS
BILL PASSED TO AUDITOR

THIS COMPLETES YOUR ORDER
RECEIVED BY ____ RECEIVING CLERK
APPROVED BY ____ FOREMAN

Fig. 19. Receiving Ticket
(Brown & Sharpe Mfg. Co.)

then enter the receipt of the goods on its record form and the receiving tickets at one operation, retain the record form, and send the receiving ticket in duplicate with goods to the requisitioning department, which signs both copies, and forwards one to the accounting department and returns the other to the purchasing department as a voucher for receipt of the goods. Fig. 18 shows a typical receiving voucher or record form, and Fig. 19 a receiving ticket.

Because of the difficulty of keeping goods and tickets together during shop transit, **identification tags** are often used as a form of receiving ticket. These tags are particularly useful when inspection is required between receiving and delivery to the requisitioning department.

If **inspection or test** of the items after receipt is required by the specifications, the receiving department must see that this inspection takes place. Often it is practical to hold goods in the receiving department pending reports on tests or inspection. Often it is more practical to transfer the goods to an inspecting or test room where the necessary apparatus is present.

Inspection prior to receipt concerns the receiving department only in that it should have on file an approval of goods before accepting them. The extent and rigidity of inspection cannot be dictated except in individual cases. Practice varies with requirements. Sometimes every unit must be inspected. In other commodities it is the practice to inspect, say, every tenth unit. In testing carload shipments of bulk raw materials, the general practice is to take samples from the top, bottom, and middle of the car. Reports of inspection results should be available to the purchasing department as guides to placing future orders.

If goods are rejected and are to be returned, or if there is a shortage or overshipment on the order, all correspondence looking to adjustment by the vendor should be conducted by the purchasing agent or the buyer. What constitutes an adjustable shortage or overshipment depends on the value of goods and trade customs. In certain trades there is a custom that a variation of 10% either way in quantity must be accepted.

Defective material to be returned should be accompanied by the inspector's report showing in detail the nature of the defect, and a requisition for replacement, if desired, should be submitted by the requisitioning department. It is usually good practice to pay for goods shipped, pending inspection, and obtain credit memoranda for any defective goods returned. In the case of vendors whose credit rating is doubtful, it is safe to hold invoices until inspection is completed and deduct for defective goods.

Returns for defects and all forms of requests for adjustments should be made only on authorization by the purchasing agent or buyer. In a large purchasing department there may be a claim clerk whose sole duty relates to defects, shortages, etc. In some cases a correspondence section attends to all correspondence with reference to defects or shortages, or adjustments for any reason.

There should be a **record of all goods returned and claims made,** this record to be closed only by receipt of a credit memorandum or replacement on a no-charge basis. This claims record preferably should be in the accounting department as a check on the purchasing department's closing of claims. It is also desirable that the purchase record contain a notation of all claims and their disposal as part of the history of the transaction, to guide buyers in the placing of future business.

HANDLING THE INVOICES.—The invoice is the vendor's bill or charge against the buyer, on the basis of which he claims payment for the goods furnished. It is based upon the purchase order and should refer to it and follow it in all details of description, terms, and prices.

When the invoice is received, it is sometimes stamped with the route through which it must pass to obtain the checkings and approvals neces-

sary for payment. A typical stamp used for this purpose follows the wording below:

Cash discount terms....................................
Entered on purchase record............................
Approved for price......................................
Buyer's approval ....
Date received in plant..................................
Receiving record No. ....
Date of receipt of goods...............................
Accounting department O. K. ....
Charged to ....
Paid by check No. ....

Routine Followed.—The date on which the invoice is received in the purchasing department is stamped on the invoice by a dating device on the stamp used. The invoice is then routed to the purchase record desk for entry and comparison with the copy of the purchase order, and to the follow-up section to which a copy of the receiving report is sent to close out the follow-up procedure. It then is passed to the price clerk for approval for price only. This price may be checked from catalog lists and discounts, from quotation records, etc. It then passes over the purchasing agent's or buyer's desk for final purchasing department approval. The invoice then leaves the purchasing department for the accounting department, where it is compared with the receiving record if this check has not been made in the purchasing department, and the date and number of the receiving record sheets are noted. The standing order or job number to which the invoice is to be charged is also entered on it, and proper charges are made against this account. A voucher requesting the drawing of a check to pay the invoice is then prepared and voucher and invoice are forwarded to the treasurer's department for payment.

Variations of this routine are many, depending on the set-up of the organization, the kind of system in use for accounting, etc. Often, as indicated above, the invoice is checked against the receiving report in the purchasing department. This plan is good practice provided the receiving department is independent of the purchasing department. In many companies entry of the job or standing order number to which goods are to be charged is made from purchasing department records and checked in the accounting department.

A variation of this routine is desirable in the case of invoices on which a discount is to be taken, when waiting for a check with receipt of goods would involve loss of discount. In such cases the invoice is checked as to charge only by the accounting department, is passed on for payment, and returns after payment to await checking for receipt of goods and comparison of quantities.

A better practice than using a stamped form on the invoice is to prepare an invoice flag, or printed form containing spaces for the entry of all the above checking data, properly initialed by the checkers, and other data which it might be desirable to record regarding the invoice.

Duplicate bills are demanded by the majority of companies. The duplicate comes to the purchasing department with the original, is stamped conspicuously to avoid confusion with original, and is used to inform the follow-up section as to shipment of orders. It is then filed in the purchasing department under the vendor's name.

Invoice Checking.—Important features of invoices which must be checked are:

1. **Quantity.** This quantity check must be made against the order or purchasing department record to guard against overshipment or undershipment of requirements. Quantity must also be checked against receiving record or receiving ticket as a means of preventing payment for goods not received. This checking may be done in the accounting department, which can refer discrepancies found to the purchasing department for adjustment. The checking may be done, however, in the purchasing department.

2. **Quality.** Invoice should not be paid, or, if it has been paid to secure cash discount, credit memorandum from the vendor should be secured provided quality is not in accordance with specification. So far as invoice is concerned, checking should be done at same time as checking against receiving record for quantity. Inspection approval or record of satisfactory test should be entered on receiving record or attached to it, and should be a prerequisite to passage of invoice by the accounting department.

3. **Prices.** The purchasing department should be primarily responsible for price paid for purchased goods. Price on invoice should be checked and approved by the purchasing agent or one of his buyers to whom that authority is delegated. The accounting department, however, should operate as a check upon purchasing department. Extensions perhaps can be more conveniently checked in the accounting department.

4. **Terms.** Terms as to f.o.b. point are a part of a price and should be checked as such. Cash discounts are to be secured by the purchasing department but the terms of such discounts should be on file in the treasurer's or financial department, since that department pays the bills.

5. **Transportation Charges.** Bills for transportation or items for transportation in bills for goods should be checked by the purchasing department for the vendor's authority to ship in the manner indicated and for f.o.b. point. They should be sent to the traffic department for approval as to rate.

The function of the accounting department in the handling of invoices is double. Its duties are:

1. To see that correct charges are made against proper job or standing order numbers
2. To check purchasing department against errors and carelessness in records or calculations.

The first of these functions is purely an accounting function and need not be discussed. As to the second, the accounting department should check the purchasing department on two points. These points are paying for goods not received, and paying excessive prices for goods received. For the first of these checks, the receiving reports should go to the accounting department and be compared with the invoices. The matter of excessive prices is not so easily checked. Explanations may be asked for variations in price not accounted for on the surface of the transaction. Stores records should contain a unit price and should be the basis for questioning purchase prices when variations in price level appear.

Another method of checking the purchasing department on prices paid is spot auditing. By this method the accounting department or auditor periodically takes certain purchase transactions and audits them, obtain-

ing from the purchasing department all data, and making an actual check of market prices, quotations received, receipt, inspection, etc.

Prompt payment of bills is important not only because of credit standing, but for efficiency of buying. The purchasing department has a real interest in prompt payment in accordance with terms. It is desirable that a strict check be kept upon movements of invoices after their receipt. They should be entered upon an invoice record sheet by the financial department, or by the invoice clerk in the purchasing department if checked first there. This invoice record is watched daily and if,

FORM 1878

BAUSCH & LOMB OPTICAL CO. NO.

INVOICE MANIFEST

TO __________ DEPT.

THE FOLLOWING INVOICES { ARE FORWARDED HEREWITH FOR YOUR RECORDS / HAVE BEEN ENTERED IN THE RECORDS OF THIS DEPARTMENT FOR THE MONTH OF __________ DATE __________ 19__

PUR. AGT'S BILL NO	DATE OF INVOICE		FROM WHOM PURCHASED	MATERIAL	AMOUNT OF INVOICE	

RECEIVED __________ SIGNED.

__________ DATE __________ 19 __________ DEPT.

FIG. 20. Invoice Record Sheet

as discount dates approach, invoices have not been checked and released, they are followed up to be paid so as to obtain the discounts. Fig. 20 is an invoice record sheet.

The form of the invoice is in the vendor's hands, but a number of companies furnish their own forms for billing and send them to the vendor with the purchase order. Fig. 21 shows a typical invoice form furnished by the buyer.

Standardization of invoice forms has many advantages in economy of clerical effort, reduction of errors, and efficient handling of invoices. The National Association of Purchasing Agents, in cooperation with the National Association of Cost Accountants and others, has developed a standard invoice form which has gained wide recognition in industry, and has been promulgated as a simplified practice recommendation by the Division of Simplified Practice, National Bureau of Standards.

DUPONT **E. I. DU PONT DE NEMOURS & COMPANY**
INCORPORATED
WILMINGTON, DELAWARE

ORIGINAL

INFORMATION FOR WHICH SPACE IS HERE PROVIDED MUST BE SUPPLIED BY SHIPPER OR INVOICE WILL BE RETURNED AND DISCOUNT CALCULATED FROM DATE CORRECT INVOICE IS RECEIVED

DU PONT ORDER No. ____
CONSIGNED TO ____
SHIPPED VIA ____
CAR NO AND INITIAL ____
ORIGINATING POINT ____
SHIPPING WEIGHT ____ LBS
PREPAID OR COLLECT

TERMS

____ DAYS NET ____ PER CENT ____ DAYS
DELIVERY F. O. B.
RECEIPTED EXPENSE BILL MUST ACCOMPANY ALL CHARGES FOR TRANSPORTATION

DU PONT VOUCHER NO. ____
SELLERS NO. ____ DATE ____
BOUGHT OF ____
STREET AND NO. ____
CITY AND STATE ____

ORIGINAL BILL OF LADING MUST ACCOMPANY THIS INVOICE

QUANTITY	DESCRIPTION	PRICE PER UNIT	AMOUNT	TOTAL	

PRICES AND TERMS CORRECT

APPROVED ____ FOR DIRECTOR OF PURCHASES

APPROVED FOR PAYMENT ONLY

ABOVE MATERIAL RECEIVED ____
AND SAME IS ____ SATISFACTORY

AMOUNT OF INVOICE

DO NOT WRITE BELOW THIS LINE

CHARGE

EXTENSIONS CORRECT

CHECKED BY ____
APPROVED BY ____

PURCHASE ORDER CHECK

CASH DISCOUNT ____
FREIGHT ____
NET $ ____

ENTERED

AUDITED

CHECK NO ____

Fig. 21. Invoice Form Supplied by Customer

Purchasing Department Records

VARIETY OF RECORDS.—The most important records to be kept by the purchasing department are:

1. Record of Material Specifications.
2. Purchase Record.
3. Contract Record.
4. Vendor Record.
5. Price or Quotation Record.
6. Summary of Purchase Work.
7. Miscellaneous Records.

RECORD OF MATERIAL SPECIFICATIONS.—All specifications for purchased material as adopted should be filed and indexed for availability and ready reference. This file should be on the purchasing agent's or buyer's desk, or located conveniently for use at time of authorizing orders. Notation of specifications should also be made on the purchase record cards.

PURCHASE RECORD.—There should be a separate purchase record card for each commodity and usually for each size or variety of each commodity. On the purchase record are entered all orders placed and sometimes all deliveries or shipments against them. Copies of purchase orders are used from which to post whatever information may be desired, such as date, quantity, price, requisition number which authorizes purchase, account number to which goods are to be charged, vendor's name, and all other facts pertinent to a complete record of the orders. From the vendors' invoices may be posted, if desired, quantity shipped, date of invoice, price, unit, discount, and terms. Some companies do not consider it necessary, however, to post each invoice to the record card, on the theory that the buyer is not interested in the invoice unless it differs from the quotation.

The record should be so arranged as to allow quick and accurate comparison between different purchases of the same commodity. This record is in many respects the heart of the purchasing routine, as it shows the buyers the facts regarding each order as to choice of vendors, previous experience as to volume of purchases, prices, etc., and allows each invoice to be checked with the corresponding facts in view. For a moderate-sized concern, however, the following information is all that is necessary:

1. Purchase order numbers.
2. Full description of materials ordered; including specification or drawing numbers.
3. List of vendors asked to quote on the orders, including date of quotation, price, f.o.b. point, freight to point of consumption, terms of payment, quantity.
4. Vendor or vendors with whom orders were placed, and a space for remarks. Under the latter heading can be placed special information as to good or poor service or quality.

Fig. 22 shows a simpler form of purchase record card than the one just described. Information is to be put on the card as follows:

1. When the bids are requested, a notation of the date and the firms from whom quotations are requested.
2. Upon receipt of quotations, prices are to be posted.
3. When the order is placed, prices, terms, and the name of the vendor are to be posted.

NO

√	PURCHASED OF	ORDER REFERENCE				DESTINATION	QUANTITY	DESCRIPTION	PRICE	F O B	INV DATE
		√	DATE	REF	ORDER NO						

PURCHASE RECORD

Fig. 22. Purchase Record Card

A modification of the purchase record can be made in the case of items carried in the storeroom. On the regular stores record card there can be considerable data, such as supplier's name, order numbers, shipping instructions, etc., as well as the usual notations of receipts, balance on hand, ordering multiples, etc. By having this card sent to the purchasing department with each new purchase requisition, and making use of the information on it, the buyer can limit the information on his card to the list of bidders, quantity, price, terms, delivery cost (including freight), and other data of concern only to the purchasing department.

CONTRACT RECORD.—It is essential to have available at all times a complete record of purchase contract commitments. The contract record should show commodity, vendor, order number, total quantity contracted for, time limits of contract, price and unit, and all other necessary information for filling the contract properly and recontracting upon expiration. There should also be spaces for posting quantities ordered or received against contract, together with a perpetual balance column. This record should be on, or near, the buyer's desk, and should be maintained by the clerical or service section. A tickler file is often used to bring contracts up for action by the buyer prior to expiration. Fig. 23 shows a simple, blanket contract record card.

VENDOR RECORD.—Records of vendors on the purchase record card may be sufficient when supplemented by directories, registers, etc., which are available. Many purchasing agents prefer, however, to keep a separate card file of vendors, arranged, and filed by commodity headings. This file constitutes a list of potential sources of supplies on various commodities and gives an opportunity for notations of confidential facts affecting each vendor's desirability as a source of supply.

The card suggested as a purchase record above can be enlarged to become a vendor record, in which case under remarks can be given the reason why a certain vendor has not been asked to quote. Such cards become more valuable with time. Folders rather than cards, covering vendors with whom business is being done or where special investigations have been made, are sometimes used. Such folders are called "Confidential Information on Suppliers." In them are kept copies of credit reports, plant inspection reports, and any other information that may be useful in determining purchasing policy.

PRICE OR QUOTATION RECORD.—The price or quotation record has been discussed previously in this Section. It consists of a quotation record file, catalogs, circulars, price lists and discount sheets, and all price information obtainable on commodities purchased. It should be in the hands of a price clerk whose sole duty is keeping the price record up to date and checking invoices.

SUMMARY OF PURCHASE WORK.—A running record of number of orders placed, number and value of invoices received, number of receipts, number of letters written and telegrams sent, etc., is a valuable aid to the purchasing agent in planning his department's work, and checking its efficient operation. The variety of items to be shown on such a summary sheet will vary greatly with the line of work done by the plant, volume of purchases, etc. It should include a record of all invoices held in the purchasing department and by whom held, to stimulate

BLANKET ORDER RECORD SHEET NO. COMMODITY

PURCHASED OF	DATE	BLANKET ORDER NO	QUANTITY	PRICE	F O B	TERMS OF PAYMENT	DELIVERY TIME LIMIT	LOW STOCK POINT

REQ. NO	RELEASE ORDER NO.	DATE	DESTINATION	QUANTITY	REQ NO	RELEASE ORDER NO.	DATE	DESTINATION	QUANTITY

CONTINUED ON SHEET NO.

COMMODITY	PURCHASED OF	BLANKET ORDER NO.

DATE	BALANCE ON HAND (PAID FOR)	INVOICE DATE	INVOICE NUMBER	TOTAL AMOUNT	TERMS OF PAYMENT	GROSS UNIT COST	ACCOUNT CHARGED

REQ. NO.	RELEASE ORDER NO.	DATE	DESTINATION	QUANTITY	ACCOUNT RELIEVED		REMARKS
					DATE	AMOUNT	

FIG. 23. Blanket Order Record (*face and reverse*)

193—

PURCHASING DEPARTMENT

	ORDERS				MISCELLANEOUS				INVOICES	
AUG	STORES	PRODUCTION	GENERAL	TOTAL	LETTERS	TELEGRAMS	REPORTS	SHIPMENTS RETURNED GOODS	NO REC'D	NO PASSED
1										
2										
3										
4										
5										
6										
7										
8										
23										
24										
25										
26										

WORK SHEET

INVOICES HELD										INVOICES HANDLED			
AT PRICE DESK		AT CARD RECORD		BY BUYERS		IN ADJUSTMENT		TOTAL		REC'D FROM TREASURY DEPT	REC'D FOR ADJUSTMENT	PASSED TO ACCOUNTING	RETURNED AFTER ADJUSTMENT
NO	VALUE	NO	VALUE	NO	VALUE	NO	VALUE	NO.	VALUE				

FIG. 24. Purchasing Department Summary-of-Work Sheet

prompt handling and approval of bills. Fig. 24 shows a purchasing department summary-of-work sheet.

MISCELLANEOUS RECORDS.—Various other records are essential to certain purchasing departments. These records will vary with the nature of the industry and other factors. Records of pattern location, possession of tools needed for manufacture of purchased goods, special arrangements of various kinds, and the like, are often necessary.

Purchase Record Systems

SYSTEMS MUST FIT THE COMPANY'S NEEDS.—Every system of purchasing set-up must be adapted to the needs of the individual company, and the forms designed and used—while following the general pattern of those previously illustrated—are satisfactory only to the extent that they give the required data and keep the necessary records in a simple, concise, easily posted, readily used, effective, and low-cost manner. It is frequently best to call upon an experienced system designer for aid, because of his broad experience in solving similar problems elsewhere. This assistance is especially necessary where the purchasing program must be very closely tied in with other plant operations. Adequate, simple, inexpensive, and efficient methods are most readily set up in this manner. A few typical examples follow.

STANDARD CARD RECORD FORMS.—The Kardex standard stock record forms shown in Fig. 25 are in regular use for both production and general stores items. In this three-form set-up an order card is in the upper pocket, and a disbursement card and title insert are in the lower pocket.

The order card has space for listing names of vendors, so that only the vendor number need be entered when an order is placed. Sections are provided for recording dates and quantities of items shipped and received from vendors. One of the most important features is the section for recording consumption by months, which gives the buyer the information needed to buy in terms of time required to consume the items.

The disbursement card furnishes the running record of receipts, disbursements, and balance on hand. With the first posting in each month, the clerk adds the "Quantity" column to secure the total disbursements for the preceding month. This figure is recapped to the monthly consumption record on the order card.

The title insert is an 8 x 2-in. folded slip of paper of which only the front ¾ in. is visible in the illustration. It provides a "home" for a removed card, and eliminates constant retyping of the ¼-in. visible margin. The printed scale at the right, over which the Graph-A-Matic signal (shaded in the illustration) within the transparency operates, shows weeks' (small figures) and months' (large figures) supply on hand.

The signal is set by the posting clerk from a comparison of the balance on hand against the current average rate of consumption. For example, if the consumption averaged 10 per month and the balance on hand was 26, there would be an 11 weeks' supply on hand, as shown in Fig. 25. Assuming that, normally, the replenishment should be received by the time the signal recedes to the 4 weeks' point indicated by the black triangle, and that the replenishment time is 4 weeks, a line is printed

NO. 1743 ARTICLE Firing Pin SEC. AISLE BIN

SPECIFICATION CAT. NO. 1-8266-8U K.P. 1103

No.	VENDORS	No.	VENDORS
1		4	
2		5	
3		6	

ORDERED								SHIPPED			RECEIVED		
Date	Ven.	Order No.	Quantity	List	Disc.	FREIGHT RATE	DEL'D COST	Date	Quant.	Weight	Date	Quant.	Weight

MONTHLY CONSUMPTION			
Mo.	19	19	19
J			
F			
M			
A			
M			
J			
J			
A			
S			
O			
N			
D			
T			
TURNOVER			

DISBURSEMENTS

Rec'd	Date	Ord. No	Quant.	Bal. O.H	Rec'd	Date	Ord. No.	Quant.	Bal. O.H	Rec'd	Date	Ord. No.	Quant.	Bal. O.H.	Rec'd	Date	Ord. No.	Quant.	Bal. O.H.

JAN | FEB | MAR | APR | MAY | JUN | AUG | SEP | OCT | NOV | DEC

1743 Firing Pin

12 14 16 18 5 6 8 10 12 16 20 24

Fig. 25. Standard Stock Record Forms

FIG. 26. Combined Purchase and Stores Control Forms

at the 8 weeks' point to remind the buyer to place an order when the signal reaches that point. If the shipment does not arrive by the time the signal reaches the 4 weeks' point, as it is moved to the left as stores are issued, follow-up action should be started.

Over the left-hand JAN to DEC scale a ¼-in. signal is set to show the month of last disbursement. Thus items that fail to move are quickly spotted and steps can be taken to dispose of them. The two signals provide an easy method of keeping inventory under control. Instead of maximums and minimums (which usually should be changed frequently), the posting clerk interprets the balance in terms of **current consumption.** The signaled slide thus spots items as to whether they are overstocked, understocked, slow-moving, to be ordered, or to be expedited items.

COMBINED PURCHASE AND STORES CONTROL SYSTEMS.—A combined purchase and stores control system used by the Gulf Oil Company for controlling the inventory and purchasing of printed forms and stationery employs the forms shown in Fig. 26. As the stock record entries show that a reorder must be put through, the reorder-requested form is filled out for the item (S-4172-5 Requisition Forms in the illustration) showing date, requisition number, destination, quantity wanted, quantity on hand, and 6 months' usage, and is sent to the printing standards department for approval. Upon approval, the card comes back and is then given, together with the purchase record card, to the buyer who writes the order and enters on the card the data as to vendor selected, approval, date, purchase order number, quantity, destination, unit price, f.o.b. point, and any remarks.

Receiving is later recorded on this card, as well as on the stock record card. For forms not stocked but printed only on special requisition, no stock record card is kept. For regular stationery items, since no printing approval is needed, no reorder-requested card is used. The stock card in the illustration is signaled at "ship" (shaded marker in illustration).

Fig. 27 shows a combined purchase and inventory control system used by the Aetna Standard Engineering Company. The purchase history card is in the upper pocket. It shows complete specifications, names of vendors, and monthly summary of issues. In addition it serves as the traveling requisition, being sent to headquarters when the item needs reordering. The information contained on it furnishes the purchasing department with all necessary data, eliminates typing of requisitions, and avoids transcription errors.

Both available and actual balances are kept on the 8 x 9-in. foldover card in the lower pocket, the available balance being reduced by quantities reserved, and the actual balance being reduced by quantities issued. Receipts increase both balances.

The Graph-A-Matic signal at the bottom, in a transparency, progresses across a calculating title insert which takes into account the variable times to receive replenishment orders. If it takes 4 weeks for delivery, a check mark (black triangle) is made on the "4" line. When the posting clerk calculates the number of weeks' supply represented by the balance, she sets the signal over this number on the "4" line (see heavy figures in far left column), in this case 8 weeks' supply. The heavy figures at the far right represent months' supply. As withdrawals are made from

stores and less and less weeks' supply remains, the signal is moved to the left. This automatically makes the signal (shaded) on the visible margin read Overstock, Normal, Order, or Follow-Up, whichever is the case. The ¼-in. signal (shaded) over the JAN to DEC scale shows the month the item last moved, calling instant attention to inactivity.

The American Laundry Machinery Company uses an adaptation of the Graph-A-Matic inventory analysis system. When a pocket is opened for posting, the forms appear as in Fig. 28. The order record at the upper left is simply a record of orders placed and received. At the upper right a separate card provides a summary record of usage over a 24 months' period and space for recording specifications and production information.

The Graph-A-Matic signal is set over a percentage scale to indicate the supply above or below the 100% or order-point quantity. To figure the order-point quantity, the number of days for delivery, as shown on the order card, is multiplied by 2 to provide a 100% safety factor against running out of stock. Any other factor can be used, such as 1¼ or 1½ to provide a 25% or 50% safety factor. Then, using the current monthly average consumption, the quantity that will be consumed in this period is calculated. For example, suppose delivery takes 20 days. Multiplying 20 by 2 gives 40 days or 1⅓ months. Assuming average monthly consumption as 45, multiply this amount by 1⅓ and get 60 as the 100% or order-point quantity.

When the order-point quantity has been calculated and noted on the summary card, the percentage of it represented by the balance on hand can be determined. The Graph-A-Matic signal is set to indicate this percentage. Thus the stores ledger clerk or other person charged with the responsibility for keeping stock in balance needs only to look over the slides to see the percentages over or under normal of each item.

Calculation of the Order Quantity.—The order quantity should be the order-point quantity or the most economical quantity to manufacture, whichever is higher. The following method and formula have been proved exceptionally accurate in determining the most economical quantity to manufacture.

EXAMPLE OF COMPUTATION OF MOST ECONOMICAL QUANTITY TO MANUFACTURE OR BUY

(Data assumed)

Item	Value
Unit cost:	
Average taken from cost records of various quantities made up (sum of materials, labor and burden) after excluding set-up cost	$ .50
Set-up cost:	
Machine set-up 34 hours at $1.00 for labor and burden	$34.00
Clerical and general charges per order	1.00
	35.00
Carrying cost:	
Interest, depreciation, storage and miscellaneous	12%
Average consumption per month	4,000
Time required to fill order	1 month
Reserve supply or safety factor	1 month
Minimum or order point:	
Reserve or safety factor	4,000
Consumption per 4 weeks	4,000
Order point, 8 weeks' supply	8,000

STOCK NUMBER **Steel - Cold Rolled** DESC. 2-1/8"

PURCHASE HISTORY

SPECIFICATIONS

MKP-1724

NO	VENDOR
1	
2	
3	
4	
5	
6	
7	

SUMMARY OF ISSUES

MO	19 TRANS.	ISSUED	19 TRANS	ISSUED	19 TRANS	ISSUED	19 TRANS.	ISSUED
JAN								
FEB								
MAR								
APR								
MAY								
JUN								
JUL								
AUG								
SEP								
OCT								
NOV								
DEC								
TOT								

PURCHASE REQUESTED			APPROVAL	ORDER PLACED BY PURCHASING DEPT.							RECEIVED						
DATE	ON HAND ON ORDER	QUANTITY WANTED		DATE	ORDER NO	QUANTITY ORDERED	UNIT PRICE	TERMS	VEN NO.	F O B.	DATE	REC D	BAL.	REC D	BAL.	REC'D	BAL.

FIG. 27. Combined Purchasing and Inventory Control Cards Using Available and Actual Balances

333.611 — Brake Pin

ITEM NO | DESCRIPTION | PART NO. | STOCK DEPT. | SECTION

2 X DELY PERIOD X AVG MO QUAN = 100%

ORDER RECORD

DATE ORDERED	ORDER NO	QUANTITY ORDERED	DATE REC D	QUANTITY RECEIVED	BALANCE DUE	NO DAYS DELIVERY

DESCRIPTION

ROUTING

MADE FROM

REQD ONE PIECE

ENG CHANGES D R B DATE

SUPERSEDES

SUPERSEDED BY

WHERE USED

MODEL	STOCK LIST OR ASSEM	QUAN.

STOCK LIST OR ASSEM	100"	110"	120"

STOCK LIST OR ASSEM

M E Q

19	NO. TOTAL	NO. AVG	100% QUAN
JAN			
FEB			
MAR			
APR			
MAY			
JUNE			
JULY			
AUG			
SEPT			
OCT			
NOV			
DEC			
JAN			
FEB			
MAR			
APR			
MAY			
JUNE			
JULY			
AUG			
SEPT			
OCT			
NOV			
DEC			

RAND INC.-11-666 GRAPH-A-MATIC INVENTORY ANALYSIS FOR PROFIT CONTROL

FIG. 28. Graphic Inventory Analysis and Signal System

Formula:

$$\sqrt{\frac{2 \times (\text{Quantity used per year}) \times (\text{Set-up cost})}{(\text{Per cent of carrying cost}) \times (\text{Unit cost})}}$$

or

$$\sqrt{\frac{2 \times 48{,}000 \times 35}{.12 \times .50}} = \sqrt{56{,}000{,}000} = 7{,}483 \text{ plus, or say } 7{,}500 \text{ or } 8{,}000$$

Reports to Management

PURCHASING DEPARTMENT REPORTS TO MANAGEMENT.—The modern concept of a purchasing department demands that there should be means for measuring its efficiency to the satisfaction of the company management.

A plan for measuring this efficiency serves a double purpose:

1. It permits management to keep an actual check upon how well the purchasing department is doing its job.
2. It permits the purchasing agent to analyze and measure his own task and his performance of it, and such a measurement is sure to result in improvement.

Factors in determining purchasing efficiency are:

1. Proved savings. These will include:
   a. Proved savings of prices paid over market prices upon goods bought.
   b. Proved savings achieved by initiation of improved methods or substitution of better or cheaper materials.
2. Expense of operating purchasing department.
3. Expense caused by purchasing department failures—which include:
   a. Purchasing loss and error account.
   b. Cost of failure to have material on hand when needed.
4. Inventory expense.

Of these factors item 1 is a credit to purchasing department's account, while items 2, 3, and 4 are debits.

To establish any yardstick of purchasing efficiency, there must be reports to management indicating the purchasing department's standing as to each of these factors. Some of these reports will originate in the purchasing department, while others must come from the materials control or the accounting departments.

Proved Savings on Price.—Proved savings on price should be established by charts or tabular reports on the principal commodities purchased, showing comparatively the average market prices of the commodities and the actual prices paid over the period covered by the report. It is impractical to keep such charts or reports on all items bought without unreasonable clerical expense, so that it is usual to maintain them on major items only, and assume that all other items are bought at market prices. From these charts or reports on individual commodities is drawn a summary of proved savings on price.

Proved Savings by Substitution.—Proved savings by substitution cannot be established merely on the claim of the purchasing department.

Other departments may have an equal claim to credit for substitutions made. It is necessary, therefore, to initiate claims for such savings in the purchasing department, then have them substantiated by the proper plant authority, and finally have each claim approved by the management before it is credited to the purchasing department. Fig. 29 shows a claim sheet for savings by substitution of material.

Savings made through substitution or
changes initiated by Purchasing Department

Commodity ....
....
Explanation ....
....
....
....
Amount claimed as saved........$4,800.00...............
Signed............................
Purchasing Agent

Approved.........................
Vice-President in charge of Production

Date................

Fig. 29. Purchasing Department Claim for Savings

Another way of proving savings is to show the differential between the price paid for a fabricated article and the market price of the component materials.

For example, for solder, grade 50–50, the metal content is established and there are published prices on lead and tin. The purchase records will show the price paid over the price of metals. If by developing a new source of supply or by developing a new method of purchasing, the differential is lowered, the purchasing department can claim the credit for the difference between the new and old differential.

It is difficult to apply an accurate yardstick to purchasing work. Gross inefficiency will soon show up, but unfortunately there is no way to prove that a job well done cannot be done still better. Methods of measuring such as cost per order, cost per dollar spent, etc., all have in them so many variables that are beyond the control of the purchasing department that without full, detailed explanation and adjustment they become misleading. Ten orders for a stock size of strip steel can be handled much more cheaply per order than one order for some fabricated item made according to special specifications, which requires special tools, samples to be submitted, etc.

Departmental Expenses.—The departmental expense of the purchasing department includes salaries and wages, stationery and supplies, light, heat, charge for premises occupied, telephone, telegraph, and postage expense, and all other expense incurred by the company in operating the department. The account should be as inclusive as possible and the report showing this expense will originate in the accounting or finance department. Fig. 30 shows a purchasing department operating expense sheet.

	January	February	March	April	etc.	Year
Salaries and Wages.......	$1,528.60	$1,503.79	$1,463.87	$......	$......	$17,143.10
Traveling Account	5.00	25.47	73.56			315.25
Stationery and Supplies..	256.78	179.54	193.56			1,767.24
Subscriptions and Dues...	75.00	15.00	63.00			285.00
Rent, Heat, Light and Equipment	312.50	312.50	312.50			3,750.00
Telephone and Telegraph	315.47	259.42	236.15			2,480.00
Excess Transportation Charges	569.73	445.02	379.81			3,144.37
Totals	3,063.08	2,740.24	2,722.45			28,885.15
Orders Issued during Period	3,600	3,155	3,325			29,697
Cost per Order...........	0.8509	0.8685	0.8188			0.9727

FIG. 30. Report of Purchasing Department Expense

Loss and Error Account.—The purchasing department loss and error account covers all expense caused by errors in specifying material, loss in receiving, shortages not adjusted by vendors, defective goods not replaced or adjusted by vendors, etc. The accounting department should keep this record and submit a report which summarizes it. Goods returned for defects should be charged to this account and credit memoranda received or replacements should be credited to it. All transportation charges on such transactions as well as handling charges should be debited except so far as borne by vendor. Fig. 31 shows a summary of the purchasing loss and error account.

Loss and Error Account Summary

Month	Amount	Month	Amount
January	$ 10.43	July	$ 12.44
February	4.17	August	5.67
March	85.96	September	189.53
April	136.38	October	75.01
May	3.77	November	3.87
June	15.23	December	80.98

Total for year ending Dec. 31, 19—........ $623.44

FIG. 31. Summary Report of Loss and Error Account

Failures to Receive Materials on Time.—There should be a definite report on failures of the purchasing department to receive material on time. So far as the accounting system provides a means for charging actual expense caused to the company by such failures, actual expense should be used. When the actual expense is not ascertainable, as is generally true, some method for making a fixed charge against the purchasing department for delivery failures should be adopted. A fair method is to charge purchasing department on each order received late with the cost of placing the order. This plan rests on the theory that the purchasing department is paid a certain sum to do a job which includes getting material by a certain date. Not having done the job, since material was not received as specified, the department should be debited with the cost

of the job. For the purpose of determining its efficiency in this respect, the purchasing department should maintain a record of orders received on time, and orders received late, with the ratio of each to total orders. Fig. 32 shows a purchasing department report on delivery of purchase orders.

	Jan.	Feb.	Mar.	Apr.	May	etc.	Total
Open orders in file 1st of month......	645	580	613	575	560	.....	.....
Orders issued during month...........	3,600	3,155	3,325	3,267	3,159		29,697
Orders received during month.........	3,665	3,122	3,363	3,282	3,224		29,950
Orders open at end of month.........	580	613	575	560	495		
Orders received on time...............	3,209	2,850	3,113	3,169	2,998		27,134
Orders received 1 day to 1 week late..	318	176	150	76	145		1,977
Orders received 1 week to 2 weeks late	90	82	69	33	60		599
Orders received later than 2 weeks....	48	14	31	4	21		240
% received on time....................	87.6%	91.3%	92.6%	96.6%	92.9%		90.6%
% received 1 day to 1 week late......	8.7	5.6	4.5	2.3	4.5		6.6
% received 1 week to 2 weeks late....	2.4	2.6	2.0	1.0	1.9		2.0
% received later than 2 weeks.........	1.3	.5	.9	.1	.7		.8

FIG. 32. Summary of Delivery of Orders

Other Reports.—Inventory carrying charges are a charge against purchasing department efficiency, whether or not the purchasing department controls inventory. This condition is true because the amount of stock carried has a direct bearing on the difficulty of the purchasing task and prices that can be obtained. A report of total inventory carried with carrying charges thereon is part of the management's record of purchasing department efficiency. This report will be initiated by the materials control department.

In addition to the above, the management should have before it a report showing in some detail a record of the activities of purchasing. Such a report should include the number of orders placed, number of invoices, average money value per order, and all other pertinent facts indicating the volume and scope of the purchasing department's activities. This report will be initiated in tne purchasing department. Fig. 33 shows a report of purchasing department activities.

	January	February	March	etc.	Total for Year
No. in Dept.	9	9	9	........:	9
Orders issued	3,600	3,158	3,325		29,697
Total purchases	$213,117.00	$175,765.48	$164,859.41		$1,234,567.89
Value per order..........	$59.20	$55.71	$49.58		$41.57
Invoices rec'd	4,487	3,996	4,416		38,062
Letters written	1,160	912	1,125		9,306
Telegrams sent	143	100	103		843
Carloads rec'd	11	8	15		131
L. C. L. rec'd	114 tons	149 tons	115 tons		1,025 tons
Parcel post	2,340	2,134	2,419		23,813
Express	524	447	429		3,868
Overland	1,160	490	690		6,352
Returns	206	175	227		1,848

FIG. 33. Purchasing Department Activities Report

EVALUATION OF PURCHASING DEPARTMENT EFFICIENCY.—With these seven reports before it, the management may proceed to evaluate the efficiency of the purchasing department. The methods used for this purpose will vary with size of company, type of purchases, and other factors. It is important that evaluation should rest upon the sound theory that the measure of efficiency shall be the ultimate cost of spending a dollar compared with the savings achieved. The master cost sheet shown in Fig. 34 indicates a method of summarizing the purchasing department's cost to the company and the job it has done.

The final index of purchasing efficiency may be stated as a percentage. The net ultimate cost of the department (including operating expense,

Master Cost Sheet for the Purchasing Department

DEBITS

Item			
Prices paid in excess of average market prices[1]			
Lumber		$1,122 85	
Foundry Scrap		642 91	
Flour		309 00	
Total			$2,074 76
Departmental Expense			
Salaries and wages		17 143 10	
Travelling account		315 25	
Stationery, supplies and postage		1,767 24	
Subscriptions, dues, etc		285 00	
Rent, heat, light, equipment		3,750 00	
Telephone and telegraph		2,480 19	
Excess transportation charges over cheapest way		3,144 37	
Total			28,885 15
Departmental Deficiency			
Losses and errors		632 44	
Deficiency in returned goods account		1,127 92	
Cost of delays			
Total orders placed	29,697		
Departmental expense	$28,885 15		
Cost per order	.9727		
2,816 orders received late,	@ 9727 each	2,739 12	
Total			4,490 48
Expense of carrying inventory of purchased goods			
Average inventory	$362 101 72		
Estimated cost of carrying	12%		
Carrying charge on inventory			43 452 21
TOTAL DEBITS			$78 902 60

CREDITS

Item		
Savings on average market prices[1]		
Pig Iron	$1,691 28	
Coke	419 88	
Coal	2,118 36	
Linseed Oil	2,148 81	
High Speed Steel	4,656 80	
Belting	764 39	
Oils and Greases	1,621 06	
	13,420 58	
Substitutions and savings, estimated (Accepted by management)	4,800 00	
Total		$18,220 58
Revenue from Salvage Sales		1,810 86
TOTAL CREDITS		20,031 44
Net cost of purchasing		58,871 16
		78,902 60

[1] These items are illustrated by use of a series of basic commodity charts furnished by the National Association of Purchasing Agents

EFFICIENCY

Item		
Total purchases for year	$1,234,567 89	
Total purchases divided into net cost of purchasing ($58,871 16)		0477
Standard of perfection		100 00%
Minus percentage of purchasing inefficiency		4 77
Percentage of Purchasing Department Efficiency		95 23%

FIG. 34. Master Cost Sheet for the Purchasing Department

cost of its failures, and cost of carrying inventory) with proved savings subtracted, divided by total volume of purchases, gives a percentage figure which is actually an expression of ultimate purchasing cost in ratio to value of goods purchased. Subtraction of this percentage from 100% gives an index figure of purchasing efficiency. Fig. 34 (The Purchasing Agent) illustrates the computation of this efficiency index.

SECTION 5

MATERIALS CONTROL AND STANDARDIZATION

CONTENTS

Standardization of Materials

Physical Inventories

SECTION 5

MATERIALS CONTROL AND STANDARDIZATION

DEFINITION AND SCOPE.—Materials control may be defined basically as constituting:

The provision of the required quantity and quality of material at the required time and place and with the minimum feasible investment.

Broadly, materials control may be considered to cover the following seven fundamental activities:

1. Planning a materials control program conforming to the sales forecasts and orders and the consequent plan of manufacturing operations laid out to cover a considerable period in advance. This planning has the objective of making available the necessary quantities of finished products at the time when needed.
2. Procurement or purchasing.
3. Receiving and incoming inspection.
4. Storing and issuing of raw materials and component parts.
5. Storing and issuing of expense or nonproductive items which comprise materials and supplies needed to carry on operations but which do not enter into the product.
6. Stores record-keeping.
7. Salvaging and conservation, covering both materials and defective work.
8. Material simplification, standardization and substitution.

This Section is concerned with the work of materials planning and the receiving, stores issuing, stores record-keeping and control, and materials standardization activities carried on in a manufacturing plant.

FUNCTION OF CONTROL.—The more complicated the type of manufacture, the more detailed will be the materials control routine, but as complications of manufacturing increase, the necessity for control becomes even more important, regardless of the kind of factory. The functions of control (Cartmell) are as follows:

1. Determining the probable materials requirements.
2. Securing an adequate supply on time and storing it if necessary.
3. Issuing and delivering stores as wanted.
4. Recording all stores transactions on suitable records.
5. Furnishing the data for cost and financial accounting relating to stores.

There are two phases of materials control:

1. Clerical—primarily the determination of requirements, preparation of requisitions, and keeping of records, together with the several auxiliary procedures.
2. Physical—primarily storing and issuing materials and checking quantities by counting, to adjust any discrepancies in stores records.

Materials are often the largest single item of cost in manufacturing, ranging from about 20% up to 90%, thus sometimes exceeding both labor and overhead expense as shown in Fig. 1 (Alford, Principles of Industrial Management). Investments in inventories may likewise be the largest item on the balance sheet with the exception of plant and equipment, and sometimes may even exceed the latter. Their most efficient utilization will therefore naturally be n important factor in the success of any manufacturing plant.

Product	Percentage (approximate) of Material Cost in Manufacturing Cost
Cement	17
Telephone equipment	21
Furniture	40 to 70
Indoor games (principally paper and pasteboard)	50
Pig iron	55
Beet sugar	65
Lead-covered cable	70
Line wire	85
Flour	90

Fig. 1. Ratio of Materials Costs to Total Manufacturing Costs

Advantages of Materials Control.—The control of materials has many vital financial and operating advantages, among which (Cornell, Organization and Management) the following are prominent:

1. Prevention of loss through check of all incoming materials as to quantity and quality, and agreement with all conditions specified on the purchase order.
2. Reduction of waste due to theft, breakage, deterioration from the elements, etc., and waste of space because of improper location and arrangement of materials stored.
3. Less overbuying and tying up of capital in inventories.
4. Reduction in the varieties of items needlessly carried.
5. Elimination of production delays by supplying the required materials in the manner and quantity needed and at the specified time.
6. Maintaining of a perpetual inventory or balance-of-stores system to assure reordering, proper recording of issues, facility for apportioning materials to current jobs, and determining amounts available for incoming orders.
7. Provision of a basis for accounting for materials received and issued, and ascertaining and charging materials costs to the respective products.

INVENTORY PROBLEMS.—The principal kinds of problems arising in the case of materials control, as outlined by Cartmell (N.A.C.A. Yearbook, 1938), are three in number:

1. Excessive inventories.
2. Inadequate accounting for materials.
3. Excessive manufacturing costs of products through the use of more expensive materials than necessary, or materials and parts that require higher labor costs than necessary.

He further points out that inventories are accumulated for five main reasons:

1. In order that materials will be on hand for production to proceed in an orderly manner and that shipments may be made to customers on short notice.
2. As the result of purchasing or processing materials in quantities sufficient to attain the optimum costs.
3. As the result of definite, long-term policies and plans for such reasons as increasing the output per production unit or dollar of investment in fixed assets, decreasing labor turnover, and increasing the continuity of employment.
4. In anticipation of periods of difficulty in obtaining materials, as occur when there are strikes in suppliers' plants or when war is threatened. This is a service reason.
5. In anticipation of higher prices or costs because of expected increases in labor rates or raw material prices. This may be pure speculation or it may be insurance against loss from higher costs without accompanying higher selling prices.

All these reasons for accumulating inventories are legitimate and logical and, when used with discretion, are sound, but good judgment must be exercised. There is no advance intention that inventories should be excessive. They become so in the course of time and in the light of future conditions which develop. Errors of judgment causing large inventories to be built up arise from:

1. Unsound forecasts of future conditions, and particularly of commodity prices.
2. Reliance upon insufficient and uncoordinated data, and inadequate procedures.

Losses from ineffective materials control can be prevented through three courses of action:

1. By establishing sound policies.
2. By installing adequate procedures so as to provide a sound basis for executing policies and exercising judgment.
3. By teaching those who exercise judgment the dividing line between sound practice and speculation.

Inventory control is one of the four vital industrial controls whose natures and purposes are as follows:

1. Budgetary control for planning all operations to secure maximum profit from a minimum investment in working and fixed capital.
2. Sales control to plan sales activities for selling the maximum quantity of the most profitable products at the lowest possible selling cost.
3. Production control to secure the maximum production of products of standard quality at lowest cost and at the right time.
4. Inventory control, or materials control, (a) to maintain inventories at a minimum consistent with sales requirements, manufacturing programs, and company policies, (b) to have a proper balance of raw materials and parts to carry on parts manufacturing and assembly work, and (c) to serve as the basis for sound purchasing.

MARGIN OF SAFETY					
REVIEWED DATE	QUAN			CODE NO.	UNIT
				TIME REQ TO PROD.	UNIT Wt/M Ft.
				MIN. ECONOMICAL RUN	UNIT Ft/M Lb.

MONTH	JANUARY				FEBRUARY				MARCH			
	DATE DUE	ORDER No	QUAN	TOTAL	DATE DUE	ORDER No.	QUAN.	TOTAL	DATE DUE	ORDER No	QUAN	TOTA
SHORT TERM FORECAST												
CUSTOMERS' ORDERS & RELEASES RECEIVED	B/F				B/F				B/F			
PRODUCTION AUTHORIZED	B/F				B/F				B/F			
FINISHED STOCK TRANSFERS	B/F				B/F				B/F			
SHIPMENTS	B/F				B/F				B/F			

FIG. 2. Materials Control Form or Cumulative

Establishing Materials Control

INITIAL STEPS IN SETTING UP CONTROL.—The initial steps in setting up control involve organization, personnel, policies, and procedures, and cover the factors of:

1. Advance planning of materials needs.
2. Organization.
3. Grouping materials into classes.
4. Standardization of materials.
5. Establishing fundamentals of production.
6. Providing physical handling and storage facilities.
7. Establishing planning, scheduling, and production control procedures.
8. Setting up stores records.
9. Auxiliary procedures.
10. Training men.

Only a few of these factors (1, 2, 3 and 7) require discussion at this point.

WIRE SIZE		REELS	TYPE No.
FIN. SIZE	HOW STOCKED —	COILS	ENG. SPEC. No.
MAT. BASE		BUNDLES	MAIN CLASS

OCTOBER				NOVEMBER				DECEMBER			
TE JE	ORDER No	QUAN.	TOTAL	DATE DUE	ORDER No	QUAN.	TOTAL	DATE DUE	ORDER No	QUAN	TOTAL
F				B/F				B/F			
/F				B/F				B/F			
/F				B/F				B/F			
/F				B/F				B/F			

Stock Record for Advanced Planning of Operations

ADVANCE PLANNING OF MATERIALS NEEDED.—The most effective way to control materials is to base the entire procedure upon programs developed from sales forecasts by kinds and quantities of product, taking into account any new plans for increasing sales, and any data developed through market studies. Often the program is laid out a year in advance, and is modified from time to time as sales of different products rise or fall, or are stimulated by new efforts. The whole objective is to streamline materials control to supply production lines kept running in close conformity with sales demands, or to build up seasonal stocks under a regulated production plan. Thus early shipping dates can be set and met, orders are processed faster, and production is streamlined, without serious danger of any material shortages and, conversely, without running inventories to needlessly high quantities. The ideal condition is to have most materials in process, little in the storeroom—to have today's receipt of materials go out in tomorrow's products.

The method of carrying on materials control under such a plan is illustrated by Fig. 2. This typical form, used in the control of cable manu-

facture, provides for 12 months' operation. The headings at the top cover materials quantity checks, manufacturing data, method of stocking, and identification of the item manufactured. The control is based upon continuous postings of the four factors listed down the lefthand margin, as soon as any of the events noted occurs or should be brought about: short-term forecast of prospective demand, customers' orders and releases (against contracts) received, production authorized, finished stock transfers, and shipments. The postings are made by months, under the upper subheadings of: date due, order number, quantity and total. The abbreviation B/F means "brought forward" from a previous sheet.

One such sheet is made out for each product. The conditions of prospective sales, actual orders, production authorized, finished stock on hand, and shipments are kept in a "flow" state and varied as trends show to be necessary. Thus, shipments are under control, rush orders can be filled from production authorized as sales forecasts and orders indicate to be necessary, overstocking can be avoided, and inventories of the raw materials themselves can be regulated to keep production supplied but not to allow materials to collect unnecessarily.

ORGANIZATION.—While some few factories place materials control under the purchasing agent and occasionally under the treasurer, by far the greatest number of plants place the responsibility and control under the production manager, who, in turn, reports to the chief manufacturing executive. In view of the fact that all manufacturing processes and costs are inherently controlled by the quality and quantity of materials available, it is only logical that the responsibility and control of all elements should be in one place. This does not mean, however, that purchasing and financial departments have no interest in inventory control. Their advice and active assistance should at all times be available. In fact, the principal criticism of placing materials control under the supervision of the production executive is that he often provides too great a factor of safety in quantities on hand. Both purchasing department and treasurer—the latter especially—exert a corrective influence on this tendency.

Under the plan stated the control of materials is under the authority of the manufacturing division of the organization, which is thus made fully responsible for carrying on this major function. Maintaining the flow of materials into the plant, through production and into finished products storage and the shipping department, is thus a completely centralized and integrated cycle. It is carried on at all points under the direction of the production planning and control section, thereby avoiding transfers of jurisdiction over materials, with the necessary check counts and other delays and the extra paper work required, and keeping the materials under actual production a larger percentage of the time. The close association of all phases of materials control with production operations—leading to the preplanning of the entire manufacturing program according to future sales plans and prospects for perhaps a year ahead, together with the modification of the production program as demand rises, falls or shifts among products—is a major step in successful business operation. In certain cases this control has been extended to the point of considering finished product as work in process.

Name	Qualifications	Responsible for	Responsible to
Purchasing agent	Market and technical knowledge; ability in buying	Procurement	General manager or factory manager
Traffic manager	Technical information concerning transportation agencies, laws, embargoes, etc.	Transportation information; all transportation to and from plant; keeping posted on rates, classifications, routings, embargoes, containers, packing methods, car-loading methods, etc.	General manager or factory manager
Materials standards engineer	Knowledge of materials, parts, products, inspection, testing, design, standardization, technical developments, and perhaps metallurgy and chemistry	Simplification and standardization of materials, suggesting substitutes, suggesting design changes, reduction of inventories	Production control supervisor, factory manager, or chief engineer
Salvage engineer	Knowledge of materials, parts, products, inspection, design, and perhaps metallurgy	Decisions on, and disposal of, rejected or borderline parts, scrap, waste, obsolete materials and parts	Production control supervisor, factory manager, chief inspector, or chief engineer
Receiving clerk	Clerical ability; some technical knowledge, common sense, and recognition of responsibility	Receipt of materials; unpacks, checks, issues notifications of acceptance or rejection	Production control supervisor or factory superintendent
Materials inspector	Knowledge of materials, parts, methods of inspection, gaging, etc.	Inspecting incoming materials and parts and rejecting defective items	Chief inspector
Storeskeeper	Knowledge of materials, passion for detail, honesty, firmness, and sense of responsibility	Receiving into storage; location; custody, counting, issuing, and protection of materials	Production control supervisor
Stores record clerk (often called balance-of-stores or materials clerk)	Accuracy; promptness in completing work, dependability; common sense; (knowledge of bookkeeping desirable)	Records of materials on hand, on order, apportioned, and available for production; notifies proper authorities when replenishments are needed	Planning or production control supervisor
Storeroom transportation clerk	Strength; care in handling, dependability, and speed	Moving materials in and out of storeroom	Storeskeeper or plant traffic manager

FIG. 3. Chief Materials Control Personnel

and therefore under the direction of the production control section, until shipped.

It must be remembered that control over materials is the key factor in industrial operation. A plant may have superlative equipment and highly efficient workers but if it should have no materials with which to work obviously it would be compelled to shut down. To the degree that materials control is not properly streamlined with sales needs and a well-planned manufacturing program, to that extent the entire plant falls off in efficiency.

Materials control is of such importance that many of the largest corporations have appointed one senior staff executive to supervise inventories continuously. Many other manufacturers have established materials committees with a control responsibility and authority, particularly in cases where close coordination of production and sales is difficult.

Organization charts covering materials control activities vary considerably among plants. The charts usually form part of those covering the production control department. A tabulation of the chief individuals concerned with materials control is given in Fig. 3 (Knowles) with an indication of the general qualifications, responsibilities, and the supervisory executive to whom the respective individuals report. Recognition of the respective functions to prevent overlapping of authority and responsibility is the main factor. Each company adopts the specific organizational arrangement which accomplishes the best results most efficiently and economically.

GROUPING MATERIAL INTO CLASSES.—Materials may be classed according to their general nature, use, or condition. Five such classes cover practically all cases:

1. **Raw materials** comprise items which must be purchased and processed to convert them into component parts, or to prepare them to go into (or be converted into) a finished product.
2. **Component parts** for the company's products are of two kinds:
   a. Parts purchased in completed form ready for assembly into a finished product.
   b. Parts made in the plant from raw materials and ready for assembly into a finished product. Such parts, if stored in semi-finished condition as may happen when final operations adapt them to different uses, are often called "worked materials."

   Both kinds may be stored also either as repair parts for customers or replacement parts to take the place of spoiled work.
3. **Supplies,** expense, nonproductive, or "indirect" items are used in operations but do not go into the finished product. Such supplies may be either purchased or manufactured. They include cutting and lubricating oils, cleaning or pickling solutions, waste and wiping rags, janitors' supplies, office supplies, construction materials, repair parts for machines and equipment, other maintenance items, etc.
4. **Work in process** includes all materials in the course of being processed or assembled into finished products. These items are those actually under operation or in temporary storage between processes in manufacturing departments. If they are definitely put into storerooms in semi-finished condition they are "worked materials," or if in finished condition they are component parts.

5. **Finished products** are units or assemblies carried in stock in completed form ready for delivery to customers. They are usually items which have been made by the company, but they may be items purchased in finished condition for purposes of resale.

The above classes, except for item 3, Supplies, are direct materials because they go into, or are, the product which is delivered to the customer. Supplies do not go into the finished product and, as noted above, are indirect materials.

ESTABLISHING, PLANNING, SCHEDULING AND PRODUCTION CONTROL PROCEDURES.—Materials control is an essential preliminary to all activities in production planning for decreasing the time interval between receipt of raw material and shipment of finished product. Straight-line movement of materials through processes, simplification and combination of manufacturing operations, and similar measures are important contributing factors.

It is not unusual to find companies in the automotive industry which maintain no raw materials stores, considering material as being "in process" immediately upon its arrival. Material usually is scheduled to be processed within a few hours of its receipt. Typical examples from representative industries of reductions in inventories, storage time, and handling costs, sometimes also attended by increases in the volume of production, are:

Improvements in materials handling: inventories cut 28%, time interval between receipt of materials and shipment of order reduced 50%. Proportionate inventory reduction, 64%.
Better planning and scheduling: 300% increase in output, 65% reduction in inventories. Proportionate inventory reduction, 85%.
Improvement in production control methods: 300% increase in output, 75% reduction of inventory. Proportionate inventory reduction, 91%.
Reorganization of planning and production control: 60% increase in output (with a 46% decrease in working force), 91% decrease in inventories. Proportionate inventory reduction, 94%.

Procedures for Materials Control

ELEMENTS IN THE PROCEDURES.—Like all plans for control of industrial operations, the control of materials requires an adequate and systematic procedure for efficiency, reliability, service to production, minimum investment, and low cost. A knowledge of this procedure is fundamental to an understanding of the principles and practices of materials control.

The Materials Control Cycle.—The cycle of procedures is as follows:

1. Determining or ascertaining all material needs.
2. Request filed with purchasing department to procure materials, or with the production control section to put through manufacturing orders for items made in the plant and stored.
3. Receiving incoming materials.
4. Inspection and release of incoming shipments, or release of manufactured parts from final inspection to go into storage.
5. Delivery to storeroom, or, in the case of purchased parts, to manufacturing department or other user.

6. Storing, according to classification and entering receipts in storeroom records.
7. Issuing to requisitioners upon authorized requests.
8. Apportioning material to current orders.
9. Entry into central stores records or "balance-of-stores" records.
10. Entry into cost and accounting records.
11. Replenishment of stores, which leads again to step 1, above.

There are three other fundamental activities which parallel the above cycle. They are:

1. Determining purchase and inventory quantities.
2. Standardization of materials.
3. Physical checks of quantities on hand.

The materials control cycle steps will be taken up in detail in the following pages, and later the three parallel fundamental activities will be discussed.

Forms Used.—The forms, lists, and records used to carry on the above procedures vary in kind and number among different industries and plants. Obviously, it is desirable to reduce the number of forms to a minimum and to make one form serve several purposes, if possible. Less than half, usually, of the forms in the following list would be used in any one plant. But, since forms, records, etc., are varied, are printed in different combinations, and are called by different names in different plants, the list is made inclusive to cover a wide range of practice.

1. Purchase requisition or request.
2. Production order requisition.
3. Receiving report.
4. Inspection report.
5. Delivered-to-stores form (incoming purchases).
6. Materials received from manufacturing orders form (parts made in the plant).
7. Identification tags (from receiving department).
8. Stores classification (usually a typed, multigraphed, or printed record, used as a basis for arranging record sheets and carrying on accounting).
9. Storeroom index.
10. Bin tags.
11. Stores record card (for storeroom use).
12. Material requisition or stores issue slip.
13. Group stores issue form.
14. Stores reservation or apportionment sheet.
15. Materials transfer form (to switch materials to another job).
16. Combined routing and requisition tag or slip.
17. Move order, requisition slip, and production control record.
18. Identification tags (for deliveries to manufacturing departments).
19. Stores credit or return slip.
20. Stores ledger or record sheet or card (for stores record clerk in production control section).
21. Unclassified stores ledger or record sheet.
22. Materials shortage slip, when materials are not on hand.
23. Notice of danger point.
24. Order to stock material—to be used when ordering material for the first time.
25. Verification slip or request for count of stores.

26. Stores count report.
27. Inventory tag.
28. Inventory sheet.

These forms, where important, will be included and described at points where their use is mentioned in the discussion.

REQUISITIONS FOR PROCURING MATERIALS.—There are three main ways in which material procurement is initiated (Davis, Purchasing and Storing):

1. Definite requisitions for specific purchases.
2. Release of a copy of the production program (process industries, or repetitive manufacture of an assembled product).
3. Blanket release of authority to purchase certain speculative materials (crude rubber, pig iron, flour, etc.).

Purchase Requisitions.—Definite requisitions for specific purchases come mainly from (1) the stores record (or inventory control) section of the production control department for items carried regularly in stores and controlled through stores records, (2) from the planning section for production items not regularly stored, or which are controlled by a production schedule, and (3) from individuals authorized to issue purchase requisitions as needs arise. The control of items carried in stores is accomplished through a perpetual inventory or balance-of-stores system, to be described later. Sometimes contracts are placed and the stores record section merely requisitions through the purchasing department against them. The nonstocked items are ordered by the planning section from data on bills of material or parts lists, with the exception of those requisitioned by the superintendent or other operating authority for materials or parts specially required for experimental jobs or other unusual uses.

Under a system of materials control it is understood that operating departments are not responsible for the kinds or quantities of items stored and do not do any ordering or requisitioning of materials for production, this work being the function of the planning and stores record section of the production control department.

Materials for industries which place contracts covering needs on release of a copy of the forthcoming production program, are frequently controlled on a "float" basis, that is, quantities are expressed in days' use. The "factory float" consists of the number of days' current output represented by the materials out on the manufacturing floors. The "stores float" is the number of days' output represented by materials in the storeroom, and the "purchase float" is the number of days' consumption of material still on order but not yet received. The production program usually is built up by months and for each product the quantity to be produced per month is stated. Analysis of the materials needed to make these quantities is made and these quantities are recorded, by materials, on stock records forms. When purchase contracts have been made for such materials, requisitioning consists in issuing authorizations from the purchasing department to the vendors to ship certain quantities against contract. New contracts are placed to cover extensive future periods when quantities in stores plus undelivered quantities on current contracts fall to stated levels. These practices apply to process industries and those engaged in repetitive manufacture of assembled products,

notably automotive plants, which also requisition materials upon release of production programs. For materials not carried in stores, or for parts to be made up from materials, purchase requisitions and production orders, respectively, must be issued.

Blanket release of authority to purchase speculative materials bought on commodity markets is employed with a view to buying at the proper price, or to protect manufacturing against market shortages, as well as to meet current needs. The control is thus one partly regulated by procurement cost or difficulty, rather than one solely to serve normal production needs. Pure speculative purchasing, that is, buying for larger quantities than will be needed for production, with the intention of selling surpluses to other uses when markets rise, is not a manufacturing venture and ordinarily should not be engaged in by the industrial plant.

Production Orders.—Many items carried in some storerooms consist of worked materials or finished parts processed in the company's own plant. These items are made from raw materials withdrawn from stores in the usual way. They are produced under manufacturing or production orders which are originated in the stores record section of the production control department when the quantity on hand reached a predetermined low, or—where the storeroom carries on the records function—by the chief storeskeeper. Material requisitions for the withdrawal of the necessary raw materials from stores are prepared by the section planning production.

ORDER REQUISITION
AND
LOW STOCK NOTICE
No.

ISSUED TO ______ DATE ______ CHARGE SYMBOL ______

NAME OF PART ______

DATE WANTED ______

FORGE MACHINE ASSEMBLE	CANCEL MANF'R PURCHASE	BASIS

OLD MAX. / NEW MAX.	OLD MIN / NEW MIN	AMOUNT ON HAND	LAST ORDER NUMBER	BAL. CLERK	SUPERVISOR	QUANTITY	UNIT

1	2	3	4	5	6	7	8	9	10	11	12

SYMBOL ______ DRAWING NO ______ SHEET ______ LOCATION IN STORES ______

REMARKS ______

FORGING ORDER NO. ______ QUANTITY ______

MACHINE ORDER NO. ______ QUANTITY ______

BALANCE CLERK ______ SUPERVISOR ______

FIG. 4. Order Requisition and Low Stock Notice

A combined purchase requisition and production order requisition and low stock notice used to request the replenishment of either stores or manufactured component parts carried in stock is shown in Fig. 4. It is issued to the purchasing department or to the particular shop in the plant which makes the part in question. Checks beside the notations "forge, machine, assemble" and "cancel, manufacture, purchase" indicate the use of the form for the individual purpose. Old and new maximums and minimums are given, together with amount on hand, last order number, initials of balance-of-stores clerk and supervisor, quantity required, and unit in which item comes. The numbered spaces can be used to show monthly consumption. Entries are provided for symbol, drawing number, sheet, location in stores, and remarks. At the bottom are spaces for showing the order numbers issued for forging or machining, if done, and the quantity received from either operation, together with signatures of supervisor and balance-of-stores clerk upon completion and posting. This form obviously can also be adapted to cover the replenishment of stocks of finished products. Figs. 4, 5, 7, 8, 9, 11, 13, 14, and 15 are from the practice of the Winchester Repeating Arms Co.

RECEIVING AND INSPECTION.—It is becoming the practice to have receiving a part of materials control, although sometimes the latter takes over after the materials are in and accepted. Essentially receiving consists in unloading and unpacking materials, checking them against the purchase order and invoice, having any necessary inspection done, making out receiving and inspection reports, putting materials into standard containers, often in standard lots, and delivering them to the storeroom. One copy of the receiving and inspection report is kept in the receiving department and others go to the purchasing department and storeroom, the latter copy finally to the stores record section.

DELIVERY TO STOREROOM.—Upon release from receiving and inspection, materials are sent to the storeroom (or user) accompanied by a copy of the receiving report, or sometimes by a delivered-to-stores form. For items processed in the plant and stored as worked materials or finished parts, a transfer-to-stores form, or a copy of the production order may be sent along, or the regular delivered-to-stores form, such as shown in Figs. 5a and 5b, may be used. Copy 1 (Fig. 5a) is made out with carbons to reproduce copy 2 (an unprinted pink slip, not shown) and copy 3 (Fig. 5b). The first copy goes to the storeroom, thence to the stores record (balance-of-stores) clerk for entry on his cards, and finally to the cost department. Entries made are self-explanatory by inspection of the form. The pink copy is a temporary memorandum held by the delivering department. Copy 3 (Fig. 5b) is signed by the storeskeeper and forms both his authorization to store the materials and his receipt for their delivery.

These forms serve also to identify the items and their sources, and the quantities delivered, so that the storeskeeper can enter the delivery in the proper records. When he has finished doing so, he forwards the forms to the stores record section for posting. Identification tags may be attached to the incoming items in the receiving department, or in the manufacturing department in the case of items produced in the plant, so that the storeskeeper can readily ascertain their exact nature.

CHARGE

MATERIAL RECEIVED
FROM MANUFACTURING ORDERS
COPY 1

CREDIT

QUANTITY CALLED FOR ON ORDER 1	QUANTITY PREVIOUSLY SENT 2	QUANTITY SENT HEREWITH 3	TOTAL QUANTITY SENT TO DATE (INCLUDING 3) 4	UNIT	SERIAL NO

DESCRIPTION

SENT FROM TO STOREROOM

WRITTEN BY DATE APPROVED BY DATE APPROVED

NOTICE TO WRITER USE ONLY SPACE BETWEEN HEAVY LINES

ACCEPTED

QUANTITY	UNIT

PRICE PER UNIT

TOTAL VALUE

DATE REC'D (STAMP)

BALANCE ON TAGS

INSPECTED DATE	INSPECTED BY	LOCATION	RECEIVED BY	TAG MADE OUT BY	ADDED TO BAL SHEET	COST MADE UP BY	COST CHECKED BY

ALL MATERIAL (FROM MANUFACTURING ORDERS) MUST BE DELIVERED TO THE STOREROOM ACCOMPANIED BY THIS FORM

COST ENTERED ON COST SHEET	COST DIV.	COST ENTERED ON BAL. SHEET

DOES THIS COMPLETE THE ORDER?

YES NO — SIGNED BY MAN DECIDING

MATERIAL RECEIVED FROM MANUFACTURING ORDERS.

(a)

CHARGE

MATERIAL RECEIVED
FROM MANUFACTURING ORDERS
COPY 3

CREDIT

QUANTITY CALLED FOR ON ORDER 1	QUANTITY PREVIOUSLY SENT 2	QUANTITY SENT HEREWITH 3	TOTAL QUANTITY SENT TO DATE (INCLUDING 3) 4	UNIT	SERIAL NO.

DESCRIPTION

SENT FROM TO STOREROOM

WRITTEN BY DATE APPROVED BY DATE APPROVED

NOTICE TO WRITER: USE ONLY SPACE BETWEEN HEAVY LINES

RECEIVED THE ABOVE MATERIAL

FOR STORES DEPT.

DOES THIS COMPLETE THE ORDER?

YES NO — SIGNED BY MAN DECIDING

(b)

FIG. 5. Material Received from Manufacturing Orders

STORING AND RECORDING.—The storeskeeper is custodian of materials, parts, supplies, and all other items carried in stores. Upon the arrival of any items from the receiving or manufacturing department, he identifies them according to the stores classification, which gives the correct name and symbol to be applied to each item stored. A storeroom index is usually necessary to indicate the location of the many items carried, particularly as it is usually difficult to arrange an entire storeroom strictly in the sequence of the classification so that the classification might serve both purposes. The stores index is usually arranged alphabetically by names of items.

Stores records for materials control purposes should be kept in the stores record section of the production control department. The forms should be designed for simplicity and the kinds of entries should be held to a minimum consistent with adequate control. Clerical costs of keeping such records may run to high figures unless special study is given to these points. The number of records kept should likewise be held to a minimum and all avoidable duplication eliminated. Therefore, there should be no detailed records maintained in the storeroom by the storeskeeper unless there appears to be no other way to maintain control over materials, that is, unless, at the time, production control or some other activity connected with the procurement or use of materials is not properly organized or functioning, and additional checks and precautions are needed as a double check to catch mistakes or detect the omissions occurring in these other departments.

In a number of cases the stores record section will keep the records of finished products as well as those for raw materials, parts, and supplies. Such a plan is adopted where production is closely tied in with the sales program and manufacturing volume is regulated directly by sales demand. If it is found that the better results are secured by allowing the sales or merchandising department to keep finished product records, then such a plan should be put into effect. But control over all materials and parts used in manufacturing, and usually of all supplies required, is best maintained under the direction of the production control department, because of the immediate and constant contact of this department with the needs and status of all manufacturing. It is likewise considered the best practice not to have the stores record section located in the storeroom, which is in the shops, but rather to keep it within the area of the production control department itself. The records are constantly in use for checking and control purposes and hence should be in the place where production control work is carried on.

Since the practice described calls for a more advanced organization and method of planning than some companies have been able to develop, bin tags and stores record cards are still used in many plants. Their purposes and use therefore require description.

Bin tags are sometimes used to keep a record, by order number, of receipts and issues, so that balances on hand can be noted on the tag after each transaction. The storeskeeper thus knows how much of each item is on hand and how fast it is moving, and can make any necessary adjustment in storage space. He can also more readily verify counts to check with the stores record section.

Sometimes stores record cards, with more information than bin tags carry, are kept in the storeroom and may constitute the regular stores

BIN TAG

SYMBOL S F B S F ½ x 1½

NAME Bolts, F.F. Hd

Steel U.S. Std.

SIZE OR DESCRIPTION ½ x 1½

LOCATION A B 2 G 4

MIN STOCK 1,500

DATE		ORDER NO.		RECEIVED	ISSUED	BALANCE
MO	DAY	NO	LOT			
10	5			Brought	forward	3,968
10	7	S.O.9874			415	3,553
10	14	S.O.9940			700	2,653
10	18	Count (Weight) loss			33	2,620
10	21	S.O.9980			1000	1,620
10	25	P O 11,352		10,000		11,620
10	29	S.C.9980		25		11,645

(Cont. over)

FIG. 6. Bin Tag (Recording is done by hand)

record system. When a stores record section is set up separately under production control as it should be, however, the storeroom records should be omitted.

Bin Tags.—A representative bin tag is shown in Fig. 6. These tags are hung on hooks at the bins or shelves where the respective items are kept. They may be posted when the transaction takes place or kept together and posted later. The material requisition and other forms should have a section for initialing the posting and should be inspected on this point by the storeskeeper before forwarding to the stores record section. Tags are used front and back. The S.O. numbers in the illustration represent shop orders for which items are issued from stores, or under which they are made in the plant and placed in stores. The P.O. numbers represent purchase orders on which shipments have arrived. The S.C. numbers represent stores credits for materials returned from jobs of the same number. Replacements for loss or shortage on shop or job orders can have regular S.O. numbers unless it is desired to distinguish them for any reason, in which case S.R. can be used with the regular number. The count of items to check the balance shown on the card would usually be made by request of the stores record clerk through a verification slip. Adjustments on bin tags and stores records should be made at once. The best practice calls for making out a stores requisition to adjust the discrepancy on the stores records and in the accounting department. The lot column on the tag may be used when incoming shipments on a purchase order or stock replenishment order come in by lots, or when a job order is put through in successive lots which it is desirable to distinguish. Otherwise it may be omitted.

In Fig. 7 is shown a bin tag for entering receipts or withdrawals and making additions or subtractions right on the tag. In the company where this bin tag is used, it is the practice for the storeskeeper to enter the balance on the receiving slip or stores requisition each time a transaction takes place, so that the stores record clerk receiving these slips can check his balances and thus adjust any discrepancies arising by calling for a recount and then making the necessary changes in the records to keep the balances exact with existing stores. The bin tag in Fig. 7 is designed to fit in a metal slot or frame so that it can be posted without removal, an advantage not always obtained with the bin tag on a hook.

Where the practice is followed of physically, or on the records, using up all the units received on a purchase or replenishment order before using any from later orders or lots (first-in first-out method) a separate bin tag may be used for each such lot. The card is headed to show the purchase or replenishment order number and quantity received. Four columns down the card suffice to show dates of withdrawals for use or returns for credit, the order numbers, the quantities withdrawn, and the remaining balances. When the last units are issued, which sometimes means taking some from a new lot to make up the required quantity, the old bin tag is canceled, the one for the new lot comes into use, and the same procedures are then followed. In the case of materials subject to deterioration, the actual lots are properly tagged, and are issued in order of arrival. If changes in design have made component parts subject to withdrawal from use, the corresponding bin tags will be so marked.

SYMBOL | LOCATION

DESCRIPTION

ORDER NO.	DATE
QUANTITY RECEIVED	UNIT

DATE	QUANTITY & BALANCE	ORDER NO.
11/6	2800	
11/8	200	S.O. 17680
	2600	
11/10	800	S.O. 17700
	1800	
11/13	5000	M.O. 3216
	6800	

TOTAL ON TAGS	STORE KEEPER

FIG. 7. Bin Tag with Sections for Addition or Subtraction to Get New Balance

Stores record cards may take the place of bin tags where they are preferred because of frequent reference and for ease of posting, or where it is not desired to have the data at each bin or shelf, or where there is a central storeroom at which the record cards are kept and bin tags are used in the local storerooms, or where both the stores record section and storeskeeping are kept together because the company feels that quicker action and closer coordination are secured by such an arrangement.

Recording Receipts.—As has been indicated, when items to be stored are received from the receiving department, or from the manufacturing departments which have had orders to make up parts for stock, the kind, condition, and count should be checked with the accompanying receiving report, delivered-to-stores form, or transfer-to-stores form. Discrepancies should be noted and reported at once for adjustment. The storeskeeper is responsible for what he receives and, in fact, must usually sign or initial such forms to acknowledge his acceptance and responsibility. When he has accounted for the delivery and posted his records, he will send the form, so initialed, to the stores record section for entry in the materials control records.

ISSUING STORES.—Materials are issued from stores only upon the presentation of duly authorized requisitions. These requisitions for production materials, or the delivery of such materials, may originate in the following ways:

1. Where **no central production control system** exists, foremen or department heads make out requisitions as materials are needed for jobs.
2. Under **regular production control,** the materials requisitions are written in the planning section, usually sent to the stores record section for apportionment or reservation on the records against the job order, are delivered with other papers to central dispatching, and are sent from there to the manufacturing department where the materials will be needed. Here the local dispatcher, or the foreman, if there is no dispatcher, will send them to the storeroom in advance of setting up the job and will thus have them delivered in time to start the work.
3. For **continuous production** (chemicals, cement, etc.), a production schedule often will be made out and materials will be forwarded to the using departments according to daily needs in accordance with this schedule. Changes in amounts forwarded will be authorized by changed production schedules. These schedules may be issued monthly, or as authorizations to run as specified until further notice.
4. Under continuous production, also, materials may be stored in the production areas and placed under control of the manufacturing departments, which make periodic checks on quantities and originate requests or requisitions for replenishment at predetermined reorder points.
5. Under **mass production of repetitive lots,** as in automobile assembly plants, materials sufficient for each day's run may be sent in from parts plants or outside vendors, under planned control from the central order control division. They are delivered directly to subassembly stations or to the main assembly lines. Some materials—usually smaller items which it would not pay to handle in small lots—may be stored in the assembly plants in quantities for a month's or longer regular production, and withdrawn to supply the assembly lines as required.
6. For **special or irregular use,** foremen, department heads, or executives may authorize the issuing of materials. Such items would consist of materials or parts to replace those damaged in production, or found unsuitable, or lacking through shortages on the first requisition.

Supplies and materials for any nonproductive purposes in the plant, office, construction, or service departments and other sections, and parts and supplies used in maintenance work, are withdrawn upon special materials requisitions authorized by the heads of any of these units. Often the maintenance department will have its own storeroom and control its own materials because of the recurring nature of its work and the need for parts and supplies at hours when the regular storerooms are closed.

In all well-run plants, it is a fixed rule that storerooms must be kept locked, outsiders must not be admitted, and no materials must be given out except upon duly authorized requisitions.

Stores Requisitions.—The important information on any materials or stores requisition includes:

1. Name and symbol or description of item wanted.
2. Quantity wanted, and unit of issue (piece, foot, pound, etc.).
3. Point to which material should be delivered—department, location, etc.
4. Date wanted.
5. Charge or order number.
6. Signature of person making out or authorizing requisition.
7. Date of signing.
8. Initials or signature of person receiving material.
9. Initials or signature of storeskeeper.

Simpler forms carry the above data, but often additional entries are needed. Fig. 8, for example, shows also stores location, new balance on

STORES SYMBOL	STORES ISSUE Only one item on this issue	CHARGE OR ORDER NUMBER

DELIVER TO	SHOP SYMBOL	NAME SHOP	LOCATION	DATE WANTED

DESCRIPTION (Specify UNIT WANTED as lbs., pieces, coils, barrels, each, etc)	UNIT WANTED QUANTITY WANTED APPROVED BY LOCATION IN STORES

NEW BAL. BIN TAG	ISSUED			PRICE	STORES VALUE	HANDLING	TOTAL COST	EXCESS
	QUANTITY	UNIT	BOOK					
			SPEC					

APPORTIONED	STOREKEEPER	BALANCE CLERK	COST CLERK	MATERIAL REC'D BY

Fig. 8. Stores Issue or Materials Requisition Form (For release of stores for manufacturing)

the bin tag, amount issued, and spaces for cost data, initials of stores record clerk who may apportion material in advance of issue, initials of "balance" or stores record clerk who posts the actual issue, and initials of the cost clerk who enters the issue on the cost records for the job. It is the usual practice to put the cost data on these slips as they are posted on the stores records, to save unnecessarily repeated work if the cost clerk is required to look up materials costs. The space for apportionment provided on the stores issue form eliminates the need for a special reservation slip to assign and hold quantities sufficient for the orders covered.

Forms like those for the issue of single kinds of material find their most frequent use when the items come under different cost-charge classi-

fications, when the items are in different storerooms, when they are issued at different times, and under job order methods of costing.

Requisitions for Worked Materials.—When the items to be issued are worked materials—that is, materials partially processed in the plant and temporarily stored pending further operations—a worked material requisition may be used in place of a stores requisition. The form of this kind shown in Fig. 9 has essentially the same information as the stores requisition of Fig. 8, although differently arranged. It is used, like Fig. 8, in connection with a balance-of-stores or perpetual inventory record system. Its main feature is that it provides an easy way to show the stores account to which the item is to be charged. In many cases the form is dispensed with.

WORKED MATERIALS SYMBOL
HOLD FOR MATERIAL ON ORDER NO.
WORKED MATERIALS ISSUED
CHARGE
ISSUE TO (SHOP SYMBOL) LOCATION DATE WANTED
ISSUED: QUANTITY UNIT
WANTED: AMOUNT UNIT
ORDER ONLY ONE ITEM ON AN ISSUE
DESCRIPTION
PRICE PER UNIT
TOTAL VALUE
DATE ISSUED (STAMP)
WRITTEN BY DATE APPROVED BY DATE APPROVED
BALANCE ON TAGS
NOTICE TO REQUISITIONER: USE ONLY SPACE BETWEEN HEAVY LINES
APPORTIONED BY DATE | LOCATION IN STORES | ISSUED BY | TAG | BAL. SHEET | EXTENDED | CHECKED
MATERIAL RECEIVED BY
If for a planned order on which material is not wanted at once, stamp here
RETURN AFTER APPORTIONING
COST COST
COPY No. 1

FIG. 9. Worked Materials Requisition Form (For release of worked materials from storeroom)

Group Stores Issues.—Where a number of items for the same production order are to go to the same manufacturing department, at the same time and from the same storeroom, considerable clerical work and stores and transportation labor are saved by the use of a group stores or group worked materials issue form on which all such items are listed, the remainder of the data being the same as with single issues. Stores record and cost record work on these forms is handled in the same way as with single issues. When the bill of materials required for a complete order can be conveniently arranged to serve as a group stores issue, as in the case of an assembly order, a form similar to Fig. 10 may be employed. This form is prepared as a master for repeated use, from which duplicates can be made, the black squares showing up white on the print.

Ink or pencil data can then be inserted to cover any particular order, giving quantity, date, lot number, a check column to show delivery, balance in stock of each part, required and delivered, cost, unit on which cost is based, and amount for each item. Total cost may be added up and brought forward from sheet to sheet and finally summarized. Special notations may be made under remarks. Authorization and filling, with dates, are indicated by names or initials of the requisitioner and storeskeeper.

SHEET NO		OF		BILL OF MATERIAL	QUANTITY		ASSEMBLY NO	
ASSEMBLY NAME					DATE ISSUED		LOT NO	

PART NO	DESCRIPTION	STK RM	REQD	DEL TO DEPT	[illegible]	CK	INVENTORY CODE NUMBER	BAL IN STK	REQD AND DELD	COST	PER	AMOUNT

REMARKS:

TOTAL THIS SHEET

TOTAL BRT FORWARD

TOTAL MATERIAL

STOCKROOM MUST ISSUE ONLY EXACT REQUIREMENTS ON THIS BILL

- ★ IN PART COLUMN INDICATES PART MADE ON ASSEMBLY ORDER. ENCLOSE BLUE PRINT IN LOT FOLDER.
- ★ IN REQD COLUMN INDICATES SUB-ASSEMBLY
- ★ IN STOCKROOM COLUMN INDICATES PART DRAWN BY DEPT AND CARRIED AS BENCH STOCK
- ★ IN DEL. TO DEPT COLUMN INDICATES PART TO BE REQD BY DEPT WHEN NEEDED DO NOT HOLD ORDER FOR SUCH PARTS.

AUTHORIZED BY DATE

FILLED BY DATE

FIG. 10. Assembly Bill of Materials Used to Make Blueprints to Serve as Group Issue Requisitions

Materials Transfers.—In cases where materials issued for one order are to be switched to another order, a material transfer (Fig. 11) is used to make the charge to the new order and credit the old. Since a new stores or worked materials requisition slip will be needed to get other materials for the old order, if it is still to be put through, the issuing and cost accounting for the new transactions will proceed automatically under regular procedures. The material transfer serves merely to switch the charges on the material already issued so that the cost accounting records may be correct.

Materials Deliveries.—The required materials asked for on a requisition will be taken from the bins or shelves for delivery to the requisitioner. There are various ways in which these stores or materials requisitions are handled and stores are moved to the required point.

1. **Workmen may go to the storeroom with the requisitions to get materials, in small plants or where no organized production control system exists. They may go, in any case, on emergency to get some special item or some replacement materials for spoiled work.**

2. **Move men from departments** may be sent by the dispatcher or foreman, with requisitions, for materials.
3. **The storeroom may have its own move men** who deliver materials, in advance of production needs.
4. **The plant transportation department** may make the deliveries through its shop express system on scheduled or special trips.
5. **Conveyors** may connect the storeroom and the user sections where a regular route and need for a regular supply exist.
6. **Materials may be stored in using departments,** as stated above, when large quantities are regularly required.

In cases 3 and 4 the production control requisitions are sent to the storeroom by the dispatcher or foreman a day or so before deliveries are due. The storeskeeper then sorts and groups the requisitions and has his

CHARGE	MATERIAL TRANSFER DO NOT SEPARATE SEND BOTH SECTIONS TO COST DIV.	CREDIT

DESCRIPTION	QUANTITY	UNIT
	PRICE	PER UNIT
	TOTAL VALUE	
WRITTEN BY DATE APPROVED BY DATE		

DELIVERED BY	RECEIVED BY	PRICED	EXTENDED	CHECKED	COST	COST

Fig. 11. Materials Transfer Order (For shifting materials to another order)

assistants make up the orders in a section of the storeroom. In this way all orders from one department may be grouped and deliveries can be economically made. For convenience, a file of requisitions, by due dates and according to departments, may be set up and the items on requisitions to be filled and delivered in any one day may be assembled and held until time for removal, the requisition date file insuring their prompt handling.

Combined Forms.—Occasionally it is possible to combine two or more kinds of forms in one. Thus a combined production and job order may be used where the routing is fixed, so that a series of perforated sections can be successively removed from the form as the job progresses through the sequential steps of production. On this form the first perforated sec-

MOVE ORDER

No.______

To ___(Storeroom)___
From ___(Planning or Production Depts.)___
Date ______

Furnish to ☐ Stores ☐ Dept. No.____ From ☐ Stores ☐ Dept. No.____

The following ☐ Prod. ☐ Nonprod. Mat'l for ☐ Production ☐ Expense

Charge ☐ Stores ☐ Dept. No.____ Acct No.____ Work Order No.____ Credit Acct. No.____

ITEM	QUANT. REQ'D	QUANT. DEL'D	UNIT PRICE	AM'T	STORE EXP.
(Name, symbol, description, etc.)					

Cost Summary	UNIT PR.	AMOUNT
Material		
Labor		
Burden		
Total		

Ordered by______

Dispersed from stores to______

By______

Date______

Duplicate copies to Mat. handling ☐ Cost Dept. ☐ Prod. Dept. ☐

Entered on balance-of-stores record and/or bin tag by
___(Storeskeeper)___
Date______

FIG. 12. Combined Move Order, Materials Requisition, Cost Summary and Production Control Form

tion is the materials issue ticket. Another example of such a combination is the form in Fig. 12 (Knowles). This form serves as a stores requisition, move order, cost summary record, and production control record. It will serve for putting through a part which has to be manufactured, or a subassembly or assembly to be put together.

Stores Credits.—If stores or worked materials are left over from any job, because the order was cut down or quantities supplied were in excess

STORES SYMBOL
S

STORES CREDITED

CREDIT

RETURNED FROM (SHOP SYMBOL) | LOCATION | DATE SENT

CREDITED: QUANTITY | UNIT

SENT: QUANTITY | UNIT | DESCRIPTION — ONLY ONE ITEM ON A CREDIT

PRICE P E R UNIT

TOTAL VALUE

(DATE RECEIVED STAMP)

WRITTEN BY | DATE | APPROVED BY | DATE APPROVED

NOTICE TO WRITER: USE ONLY SPACE ENCLOSED BY HEAVY LINES

MATERIAL RECEIVED BY

INSPECTED BY | DATE | LOCATION IN STORES | RECEIVED BY | TAG | BAL. SHEET | EXTENDED | CHECKED

BALANCE ON TAGS

DISPOSITION—IF NOT PLACED IN STORES | COST | COST

SALVAGE PLANNER

ORIGINAL

Fig. 13. Stores Credit Form Used When Materials Are Returned to the Storeroom

STORES SYMBOL
S

MOVE TICKET FOR STORES CREDITED

CREDIT

RETURNED FROM (SHOP SYMBOL) | LOCATION | DATE SENT

WRITTEN BY | DATE | APPROVED BY | DATE APPROVED

NOTICE TO WRITER · USE ONLY SPACE ENCLOSED BY HEAVY LINES

RECEIVED THE ABOVE MATERIAL FROM ______

______ FOR STORES DEPT.

TRANSPORTATION SHOP RETAINS THIS COPY

DUPLICATE

Fig. 14. Move Ticket Copy of Stores Credit Form in Fig. 13

of needs, they may be returned to the storeroom with a stores credit form (Fig. 13) of essentially the same make-up as the stores issue slip of Fig. 8. When it is not desired to place the items in stores, they are sent to the salvage planner, who determines their disposition and enters the notation and his signature on the form. A carbon of this form (Fig. 14), without the entry spaces for credits or disposal, is used as a move ticket and is retained by the shop transportation department after signature by the storeskeeper.

APPORTIONING STORED MATERIALS TO ORDERS.— In the fore part of this Section emphasis was placed upon the importance of preplanning to fit the materials control program definitely into the schedules of production, which in turn is planned in advance to conform to future sales demands. Under this plan, which is followed by a growing number of manufacturing concerns in many lines of industry—even those not engaged in standardized product manufacture—the apportioning of materials is carried on in originating the production programs. When the kinds and quantities of products to be made in the forthcoming period are scheduled, materials are ordered in kinds and amounts to carry on such production and deliver finished products at the times specified. In other words, the materials flow in at a rate to keep production going and are thus actually apportioned when ordered under purchase contracts. Variations in actual production as compared with the forecast are handled by increasing or decreasing the successive purchase orders or delivery-on-contract schedules, as put through.

Where conditions such as the nature of the business, inefficiencies in making sales forecasts or controlling production, lack of a capable staff to administer the procedure, or some other cause, do not permit a coordinated master plan to be put into effect, a more detailed and localized control is needed, but the clerical cost of the work is relatively higher. A greater burden is likewise placed on the stores record system itself. In all cases, however, all materials should be apportioned to production in advance so that material shortages may be eliminated.

The plan followed is to set up the stores records so that, by inclusion of apportioning and available columns, materials may be allotted to current orders in advance of production. This plan avoids running short as may be the case when the records show only the balance on hand of the needed items and not how much of each will be withdrawn for work still to go into manufacturing. The procedure followed is to send the materials requisition slips written during the planning of the order for production, or the bill of materials where this form can be more readily applied, to the stores record clerk so that he may enter in the apportioned column on the card for each item the quantity to be reserved and the order number to which it will be applied. He then subtracts this same quantity from the balance in the available column to show how much remains for future orders. When asked subsequently to check a bill of materials for a new order coming through, to find out the materials status, he can indicate by checks against the respective items on the list the ones for which there are sufficient materials available, knowing that these materials will not be required for any work previously planned to go into production. Stores are replenished when the available balances reach stated reduced levels and there is thus

maintained a cushion stock sufficient for the regular course of production; any unusual forthcoming demands can be met by putting through purchase requisitions while such large new orders are being planned, in time to get deliveries made before the materials must actually go into production.

These procedures are illustrated on the stores record or balance-of-stores forms shown in the discussion immediately following.

STORES RECORD FORMS AND ENTRIES.—The practically universal use of stores record forms implies a wide knowledge of their application. Essentially they must contain certain basic information but must be designed for the needs of the individual company where they are to be used. Poorly drawn up forms omit important information, call for entry of unnecessary information, and are so badly laid out that a vast amount of clerical time and cost is wasted in the posting, which is a continual process in many plants. Only essential data and entries should be called for.

Component Parts Record.—In Fig. 15 is shown a component parts stores record card (4 x 6 in.) having a minimum number of entries but providing for the recording of purchase orders, quantities received and balances to come, quantities issued and job numbers, balances on hand, apportionments and job numbers, price and total cost of quantities bought.

Washer - 3/4"	Stores Symbol	Unit	Min
	SVMS	Ea	5,000
	Location in Stores: AD-4-F-5		

Date	Order No.	Quantity Ordered	Bal. on Order	Quantity Received	Quantity Issued	Issued To	Balance on Hand	Date	Price	Total Cost
5-11	7428	30,000					5,000	6-1	.005	$50.00
6-1	7428		20,000	10,000			15,000			
6-8					5,000	SO-1875	10,000			
								Date	Appor. to	Order No.
								5-11	10,000	SO-1875

FIG. 15. Component Parts Stores Record

Complete Stores Record or Balance-of-Stores Form.—In Fig. 16 is shown a typical stores record form, accompanied by an explanation of entries, which may be printed on cards or loose-leaf ledger sheets in any convenient standard size and serves most normal needs for a comprehensive record in the usual manufacturing plant. The headings are representative and may be changed as desired to fit any stores system. The

STORES RECORD

Name Bushing, Bronze — Symbol SBBB 1 x 1¾ x 2

Description 1″ i.d. x 1¾″ o.d. x 2″ long — Unit Each

Specification No. 2,240 — Dwg. No. C-14750 — Part No. W-16842

Minimum economic order quantity 6,000 — Requisition when available shows 1,500 — Location in stores AC3F4

Date	Order No. (Shop or Purchase Order)	1—Ordered (But not delivered)			2—On Hand (In the storeroom)					3—Apportioned (Not yet issued)		4—Available (For new orders)
		Req. No.	Quantity	Total	Received	Issued	Balance	Unit Price	Total Value	Quantity	Total	Quantity
Jan. 3					Inv'y		3,000	$ .09	$270.00			3,000
4	S. O. 115					300	2,700	.09	243.00			2,700
5	S. O. 131									+200	200	2,500
7	S. O. 156									+700	900	1,800
10	S. O. 131					200	2,500	.09	225.00	−200	700	
11	S. O. 210									+400	1,100	1,400
11		Req. 230	6,000									
14	S. O. 115				(credit)	+50	2,550	.09	229.50			1,450
15	S. O. 156					700	1,850	.09	166.50	−700	400	
18	P. O. 471		+6,000	6,000								7,450
19	S. O. 275									+300	700	7,150
21	S. O. 210					400	1,450	.09	130.50	−400	300	
27	P. O. 471		−6,000	0,000	6,000		6,000	.10	600.00			
							7,450	.0980	730.50			
28	S. O. 131				(Repl.)	20	7,430	.0980	731.96			7,130
31	S. O. 275					300	7,130	.0980	702.56	−300	000	

Fig. 16. Stores Record or Balance-of-Stores Form.

EXPLANATION FOR FIG. 16

Entry Date	Kind of Entry	Procedure in Making Entry
Jan. 3	Inventory	Assume that sheet is started from physical inventory (Equation: 0 + 3,000 = 0 + 3,000).
4	Issue	System just started so this order was not preapportioned.
5	Apportion	Balance on hand (2,700) unchanged but quantity available reduced (= 2,500).
7	Apportion	Add to total apportioned (= 900), subtract from available (= 1,800).
10	Issue	Subtract from balance (= 2,500) and from apportioned (= 700).
11	Apportion	Add to total apportioned (= 1,100), subtract from available (= 1,400).
11	Requisition	Available (= 1,400) is now below 1,500, the reorder point. Standard purchase amount is requisitioned for ordering by purchasing department (if a purchased item).
14	Credit	Received back from previously issued shop order. Add to balance (= 2,550) and to available (= 1,450).
15	Issue	Subtract from balance (= 1,850) and from apportioned (= 400).
Jan. 18	Purchase	Standard order placed. Ordered (= 6,000) is considered to be bought to arrive before stock falls below cushion or reserve, therefore to be available for planning future manufacturing (= 7,450). Some authorities do not count purchases as available until actually received.
19	Apportion	Add to apportioned (= 700), subtract from available (= 7,150).
21	Issue	Subtract from balance (= 1,450) and from apportioned (= 300).
27	Receipt	Subtract from ordered (= zero), post to received, insert in balance column, put unit price and total value of new order in their respective columns.
	Calculation	Add old balance and new receipt (= 7,450), add old and new values (= $730.50). Divide: $730.50 ÷ 7,450 = .0980, new unit price under average method.
28	Replacement	Spoilage or shortage on shop order. Subtract from balance (= 7,430), price valuation of balance at new unit rate, subtract from available (= 7,130).
31	Issue	Subtract from balance (= 7,130) and from apportioned (= zero).

The total value is recalculated whenever the balance is increased by receipts or reduced by issues, and at the unit price of that date. The equation, **Ordered (total) + On hand (balance) = Apportioned (total) + Available (quantity)**, can be checked at any point by taking the last entry in each of these columns and inserting it in the equation. If the equation does not balance, an error has been made in posting.

columns are the minimum number needed, and may be increased in number if additional data are required, or if it is desired to have order numbers and dates appear immediately adjacent to the respective postings instead of all at the left. One line across the entire sheet is used for each transaction even though this plan leaves spaces blank in several of the columns. Since the on-hand column tends to fill up ahead of the others anyway, and since it is desirable to have the final entries in all columns visible at the same time without turning the card or page, it will not conserve paper or space under this system to crowd the postings in the individual columns to the top of the column. The records, moreover, can be inspected to obtain data much more quickly under this plan.

Fig. 16 is the general type of form growing out of the practice of Taylor, Gantt, Barth, and others of this group. Where considered helpful, the sequence of columns shown in the form can be changed, a good arrangement being: 1—Ordered, 3—Apportioned, 4—Available, 2—On Hand.

The principle behind this form is expressed in the equation between the following quantities:

$$\text{Amount on order (total)} + \text{Amount on hand (balance)}$$
$$= \text{Amount apportioned (total)} + \text{Amount available}$$

All postings may be checked against this equation to test the correctness of the record, the last entry in each column being the one used in the equation.

In the illustration shown, the unit cost or price of the item and the total value of the amount (inventory) on hand is included and the stores record clerk posts such data, in the case of received materials, from information supplied by the purchasing department through copies of the purchase order, for prices and amounts ordered, and receiving reports for the quantities actually received, the amount of any cash discount being deducted and the cost of freight added to get the cost delivered. For issues, he uses the unit costs thus determined. In the illustration the average method of costs is used as shown in one of the calculations. Other methods—standard cost, first-in first-out, etc.—are also used according to the accounting procedures of individual companies. The stores record clerk performs these calculations and entries so that he can price the materials requisition slips as he posts issues of material, thus saving duplication of certain handlings and operations by the cost accounting department, and so that inventory value summaries may be made up rapidly for accounting reports and financial statements from the source which has the latest assembled data on this point at any one time. When a standard cost system is in use in the company, the current cost of the item is entered at the top of the sheet or card and the stores record clerk does not have any calculations to perform. When the standard is changed, he is notified to change his entry on the card.

The use of the method "Minimum economic order quantity .... Requisition when available shows ....," in place of maximum and minimum amounts has definite advantages. Maximum and minimum amounts represent conditions, respectively, when purchase orders have just been delivered and when the stock is at its lowest ebb. One is a peak quantity and the other a condition of potential danger—in both cases an extreme which should be taken care of in planning the entire control program.

The quantity to order is the economic amount determined by actual or implied agreement between purchasing, production control, and manufacturing departments to be the most economic quantity, and all parties concerned having this information. By fixing the time of reordering at the point when the quantity available falls to a predetermined level, reordering follows current consumption but fixes a tentative order point. The stores record clerk merely watches the available column and follows instructions on the sheet. These two quantities are usually entered in pencil because they must be occasionally changed as the use of the individual materials goes up or down with the course of the business. At the same time, the purchasing agent may suggest increasing or decreasing the quantity if market conditions and prices are unfavorable. In addition, definite periods for review of such quantities should be set and the quantities should also be checked at each reordering.

Some forms show at the top or side a section for entry of the total monthly consumption for two or more successive years. Others provide date and order number columns in each section of the entry records instead of at the left only, as in Fig. 16.

When a company prefers to omit the inventory value data from the stores records, even though the dollar value of the inventory is desired monthly, the quantity balance can be extended to a price balance when the need arises. A good way to secure total inventory value, usually by material classifications, is to carry a separate summary record for each stores ledger or group of stores cards, with each classification as a minimum for a group.

Under this method, a daily dollar value is secured by (1) costing requisitions as they clear through the stores records, (2) sorting costed requisitions by material classification, (3) totaling them, and (4) posting the totals to the disbursement columns of the summary cards. Receipts are accumulated in a similar manner. While more than one item will usually appear on the posting media (invoices), the fact that most vendors' materials fall into only one classification simplifies the distribution. Transportation costs and discounts, of course, must be prorated.

Systems with Cards on Rotary Drums.—Stores record systems are now obtainable in the form of large rotary drums on the rims of which are holders for mounting notched or slotted cards separated into groups by index guides or markers. These mechanisms (Wheeldex, Cardineer) come in various sizes from desk variety up to cabinet sizes holding 5,000 to 6,000 cards. From 25,000 to 50,000 cards can be brought within the working area of an operator, in the latter case by the installation of several cabinets, and in the former by the same means or by providing a large semi-circular desk with wells for the drums and a specially equipped swinging swivel chair to cover the arc of this desk. A card used in the former system, and resembling the stores ledger records previously described, is shown in Fig. 17. This equipment is likewise used for purchasing, production control, personnel, and other records, with suitably printed cards.

Use of Colors to Distinguish Record Forms.—For quicker distinction between kinds of items and greater ease of operation and control,

GENERAL WATER HEATER CORP.						INVENTORY CONTROL CARD								
ORDERED				DATE	RECEIVED		BALANCE		ISSUED		APPORTIONED			BALANCE AVAILABLE
DATE	ORDER NO	QUANTITY			ORD	QUANTITY	QUANTITY	UNIT COST	ORDER NO	QUAN	DATE	ORDER NO	QUANTITY	
	R													
	R													
	R													
	R													
	R													
	R													
	R													
	R													
	R													
	R													

MIN. | AV USED MONTHLY | DELIVERY TIME | UNIT OF MEASURE | UNIT WEIGHT | STOCK LOCATION | ☐ PURCH

MAX. | ORDER QUANTITY | MATERIAL | ☐ MFG

PART NO. | DESCRIPTION

FIG. 17. Inventory Control Card for Use in Wheeldex System

STANDARD COMMERCIAL PARTS COMMITMENTS

CONTRACT REQUIREMENTS + % TOTAL REQUIRED

SPECIFICATIONS

DATE	PUR. ORDER	REC. REPORT	FOLIO	VENDOR	ON ORDER			RECEIPTS		DUE ON ORDER	
					QUANTITY	UNIT	VALUE	QUANTITY	VALUE	QUANTITY	VALUE

STANDARD COMMERCIAL PARTS INVENTORY

RECEIPTS					ISSUED					BALANCE				
DATE	REC. REPORT	QUANTITY	UNIT	VALUE	DATE	SOURCE	QUANTITY	UNIT	VALUE	DATE	CHECKED	QUANTITY	AV. UNIT	VALUE

WORK ORDER	PART NO.	DESCRIPTION

FIG. 18. Commercial Parts Commitments and Inventory Record

CONSIGNED MATERIAL

CONTRACT REQUIREMENTS + % TOTAL REQUIRED

SPECIFICATIONS

DATE	PUR. ORDER	SHIP. MEMO	VENDOR	ON ORDER			REC. REPORT	RECEIPTS		DUE ON ORDER	
				QUANTITY	UNIT	VALUE		QUANTITY	VALUE	QUANTITY	VALUE

SUB CONTRACT COMMITMENTS

CONTRACT REQUIREMENTS + % TOTAL REQUIRED

SPECIFICATIONS

DATE	PUR ORDER	SHIP. MEMO	VENDOR	ON ORDER			REC. REPORT	RECEIPTS		DUE ON ORDER	
				QUANTITY	UNIT	VALUE		QUANTITY	VALUE	QUANTITY	VALUE

WORK ORDER PART NO. DESCRIPTION

Fig. 19. Consigned Material Order and Subcontract Commitments Record

cards of different colors are used for different general classes of items. One company utilizing the drum variety of equipment just described has buff cards headed "raw material," salmon cards headed "purchased part," and green cards headed "manufactured part." The stores records of items carried are made up on the cards of the color which designates in which class they belong. Another company substituted for a single foldover materials control form a series of three foldover forms—one in buff for standard commercial parts with the foldover front as in the upper view of Fig. 18 (commitments) and the main portion underneath as in the lower view of Fig. 18 (inventory), this latter carrying the visible index shown. The raw materials card is printed the same (commitments on the front, inventory underneath), except for the name heading and the color, which is salmon. The third form for consigned material is in light blue, the foldover front being as shown in the top view of Fig. 19 and the main portion underneath, carrying the visible index, printed as shown in the lower view of Fig. 19.

Visible Index Record Card Systems.—The system shown in Fig. 20 is used by Fairchild Aircraft for the control of materials for production orders or contracts. The visible index (bottom left) shows the kind of material covered by the card, and the signal at this location is set over the number corresponding to the plane model for which this material is needed. When new plane orders are received on which this material is needed, the right-hand signal is moved over the "order" space on the bottom margin. The cards thus signaled are then checked by use of the material requirements cards in these pockets, on which in each case are shown the model numbers on which the material is used, the numbers and names of the parts made from it, and the quantity of material required for each part and the number of parts required for each ship. The requirements for each contract are then calculated and posted on the delivery schedule chart in terms of the amounts needed each month. Total monthly requirements and receipts, with cumulative totals, are entered at the right of this card. The lower card is used for receipts and disbursements and determining the balance in stock. The Kardex Graph-A-Matic signal at the right of the lower card is set at the month in which the material is required and thus facilitates the purchase, follow-up, and delivery of the material.

Uniform Signaling of Reorder Points.—A system used by the DeVilbiss Company and others for materials control features a Graph-A-Matic signaling plan which brings the reorder points, at which purchase orders to replenish stores must be issued, of all stored items at the same horizontal position in a Kardex visible index system. Since reorder **quantities** differ, it is necessary to have a scale system to reduce all quantities to a common charting denominator. For this purpose a series of four number charts are printed, one being shown in Fig. 21. Down the centers of these charts a heavy black band is printed and the numbers to the immediate left of this line run vertically down in numerical sequence—on the first chart from 10 to 32, on the second from 33 to 55, on the third from 56 to 78, on the fourth from 79 to 99. Charts 1 and 2 are on the same card, front and back. Charts 3 and 4 are on another card, the illustration showing chart 3. These numbers are used for reorder points. The horizontal lines of numbers across the card are, to

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
MATERIAL
SPEC.
SIZE
CARD NO
CONTRACT
SUB-CONTRACT
QUANTITY SHIPS
CHARGE A/C
AMOUNT RESERVED
AM'T UNRESERVED
ORDER QUANTITY
VENDOR
PURCHASE ORDER
PURCHASE DATE
DELIVERY SCHEDULE
7 JULY
SIZE
FOR MODELS
PART NO
PART NAME
QUAN. PER SHIP IN
MATERIAL
SPEC.
CONVERSION FACTOR
PART NO.
PART NAME
QUAN. PER SHIP IN
FAIRCHILD AIRCRAFT

Fig. 20. Stores Record Card Used for Control of Materials on Manufacturing Contracts (The two cards shown in the upper portion of the illustration are filed in the upper pocket, one behind the other.)

PART NO | DESCRIPTION | STD COST

SPECIFICATIONS | WEIGHT

PATTERN

PURCHASE REQUISITION — DE VILBISS CO TOLEDO OHIO

VEN			
1		4	
2		5	
3		6	

STOCK		REQUISITIONED				ORDERED									
AVAIL	ON ORDER	DATE	O K	DATE WANTED	QUANT	DATE PURCH	VEN	P O NO	ROUTE TO	DOCK	PRICE	PER	F O B	O K	DATE PROM

USAGE														USED ON
MONTHS	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	TOTAL	
19														
19														

FIG. 21. Materials Control Records with Uniform Signaling of the Reorder Points

the right, in a sequence of which the last in each case is about three times the number on the left of the black band. Such numbers thus are 300% of their corresponding order points. The numbers to the far left of each line represent dangerous lows.

The number charts are perforated horizontally under each line so that they may be folded at the number representing a reorder point and put through a slit in the stores record card, thus showing on the visible margin at the lower right (see Fig. 21). The illustration shows that the number sheet for this item was folded along the 15, 30......160, 210 line. If this number series represents single units, 70 is the reorder point, 210 is 300% of the reorder point, and the Graph-A-Matic signal set over 50 shows that the stock is getting somewhat low, while 15 is an emergency situation. To provide for indicating larger amounts, a color system was adopted for the charts. Buff cards are used where single units are involved, as in the above example. Pink cards are used where the indicating numbers are in multiples of 10 (70 on a pink card thus representing 700), and blue cards where the numbers are in multiples of 100 (70 on a blue card thus representing 7,000). Reorder points running from 10 to 9,900 are thus provided. Scales with smaller numbers are available for control of tool replenishment and other purposes.

Reorder points for all items, regardless of actual quantities involved, thus are in the same vertical line, as are likewise 300% of reorder points and also the danger points. The horizontal positions of the individual signals, however, show what relation the quantities on hand bear to the existing demand for the individual items.

Under this system, reservations or apportionments of material are made on the stores record or inventory cards, and available as well as actual balances are recorded, in addition to receipts and issues. The purchase requisition card shown in the top pocket is removed and sent to the purchasing department when the reorder point is reached, the amount on hand and on order being shown, together with the date of request and of desired delivery, quantity wanted, O.K. of the stores record clerk, and monthly usage of the material. The data covering the purchase are filled in as the transaction is put through and the card is then returned to the stores record division. When the purchase card is sent out, the signal at the left bottom of the stores record card is set to indicate this date, as a follow-up on ordering. After the order is placed, the signal may be used to indicate when to make a follow-up, or to show the promised shipping date.

Control Cards for Manufactured Parts.—A materials control system for parts made within the plant is shown in Fig. 22. The bottom card is for the regular stores record of quantities received, used or issued, and balances on hand, without provision for apportionments or reservations for forthcoming orders, but including a column for cumulative monthly consumption. In the top of the pocket is a card in which a record of stores replenishment orders is kept, by date, order number, quantity ordered, amounts received, which often come along in lots as the shop is able to handle the production, and balances to come. Another card is provided on which the cost of set-up and total cost per unit, hundred, or lot, and the average replacement time are entered, and a record is kept, by year and month, of the quantities received on the successive orders put through.

The three separate record forms and the title insert are used in the one pocket. They provide a permanent index and a method for the accumulation of important statistical data on both the order record card and the monthly recap card, regardless of how quickly the in-out and balance record card is filled up.

The signal at the left in Fig. 22 is set over the month when the next purchase should be made. The Graph-A-Matic signal at the right indicates the number of weeks' (small numbers) or months' (large numbers) supply on hand at the current rate of consumption. This control gives a basis for stepping up turnover rates.

Control of Inventory Turnover.—An important purpose of materials control is to hold down quantities carried in inventories, so as to increase the number of turnovers per year but without reducing the amounts on hand to the point where shortages may endanger production. When the proper records have been set up, graphical methods are often important aids in maintaining stocks and at the same time holding to economic rates of turnover. Under the Graph-A-Matic method of control illustrated on records in Figs. 20, 21, and 22 in this Section, and on similar forms, various signal combinations may be set up so that the control is accomplished by visual inspection or check of the signals, followed by appropriate action. Usually two kinds of signals are used, one to indicate some date on which action occurred or should occur, the other to show condition of stocks. Thus a common plan is to set the small left-hand signal shown on the illustrations at the month of last disbursement or the month when condition was last checked, and the right-hand (Graph-A-Matic) signal to show number of weeks' or months' supply on hand, percentage of stock as compared to indicators (overstock, order point, normal, low stock, and follow-up or danger point), or other control factors.

Materials Control Board System.—Another system for handling stores records is that developed by the McCaskey Register Co. The spring-clip boards as used in production are applied in keeping stores records. Four types of forms are used—receiving slip, which can also be used as a materials credit slip, materials requisition and stock record, materials credit, stock inventory, and permanent stock cards. The two former are carbon-backed and are made out in triplicate (receiving—blue, salmon, pink; requisition—white, pink, salmon). The stock inventory is in duplicate (pink, salmon) and the permanent record (blue) is a folded tab card made out singly.

One set of boards is usually located in the storeroom and another in the stores record department, but a single control is used in some cases. The clips are mounted on boards in rows running horizontally and vertically; the boards constitute panels which are used on both sides, and they are mounted on wall brackets so that a series can be grouped together and swung back to give access to whatever board is wanted. The clips are numbered to correspond to the bin or shelf-location number where the material is stored. A visible index system serves to show the bin for any item in stores and its corresponding clip-board number.

Receiving slips are made out in the receiving department (or if used for stores credits, in the department from which the material is returned) and sent to the purchasing department and the storeroom, with

PART NO. 3053 Crank Shaft Starting Pin
DATE
ORDER NO
QUANT ORDERED
REC'D
BAL.
REC'D
BAL.
REC'D
BAL.
STOCK RECORD
PART NO. 3053 Crank Shaft Starting Pin
COST PER C
SET-UP COST
AVE. REPLACEMENT TIME
MO.
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEP.
OCT.
NOV.
DEC
TOTAL
AVE
REMINGTON RAND INC
STOCK RECORD

ITEM

IN-OUT AND BALANCE RECORD

DATE	ORDER NO.	RECEIVED	USED	TOTAL MONTH TO DATE	BALANCE	DATE	ORDER NO	RECEIVED	USED	TOTAL MONTH TO DATE	BALANCE

JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC

3053 Crank Shaft Starting Pin

9 10 12 14 16 18 5 6 8 10 12 16 20 24

FIG. 22. Stores Record Cards Covering Manufactured Parts

FIG. 23. Spring-Clip Board for Stores Control (Duplicate system in storeroom and stores record section)

the material. When the material is checked and stored, the storeskeeper takes the slip from the receiving department on which the new quantity appears, goes to the corresponding clip on the board (see Fig. 23, clip 63), writes from the top (last-posted) ticket appearing under this clip the previous balance, which becomes the in-stock entry (300) on the new receiving slip, adds the new amount received (2,000) and obtains the new total (2,300). He then files the blue copy on top under the clip (63) to show the latest condition and sends the salmon and pink carbons to

REG NO. 63 | MINIMUM 1,000 | PRICE 5¢

Part No. A 2875

Description 17 A Switch

DATE ORDERED	QUANTITY	ORDERED FROM	DATE REC'D	QUANTITY	PRICE	PER	AMOUNT	TERMS	FREIGHT-EXPRESS
9-15-	3,000	General Mfg	9-26	3,000	05	Ea			
1-7-	4,000	Eastern Supply	1-17	4,000	05	Ea			
3-31-	2,000	" "	4-10	2,000	05	Ea			

FIG. 24. Permanent Stores Card for Spring-Clip Board System

the stores record section for the same purpose on the board there. As he receives materials requisitions he fills them, goes to the board for this bin (see Fig. 23, clip 62), copies from the top card the previous balance, which becomes the in-stock entry (1,500) on the new white requisition slip, subtracts the new amount issued (500) and obtains the new total (1,000). He then forwards the pink and salmon carbons to the stores record section. Stores credits are handled like receiving slips.

The stores record clerk checks each slip as it comes along and verifies it with the previous tickets for the same item. Then he enters the necessary cost data, which are not recorded in the storeroom, posts his copy of the ticket on his board according to bin number, and sends the carbon to the cost department, accounting department, or wherever else designated. Additional copies of tickets can be provided in the system if more are needed. The boards in the storeroom and stores record department are identical as to postings. Stock inventory checks (and periodic physical inventories, for which special report and summary forms are used) can be made in the same way as under other systems, and the tickets handled as above to show the check or make corrections in quantities. The stock inventory tickets call for quantity, price, unit, and amount entries. For group issues, apportioning of material, and other purposes, the system is varied slightly to conform to needs.

The tabbed permanent stock card (Fig. 24) is used only in the stores record section. It is folded at the vertical line beside the price tab, when filed, and is placed behind all of the tickets under the clip where it goes (bin tab, 63); with the tabs showing above these tickets. The minimum (reorder) quantity shows on the middle tab so that when the balance falls to this figure a reorder requisition can be placed, a copy of which may go on the board under the clip as a record. The price tab is used for quick reference in entering costs on requisitions. A permanent record of purchase or manufacturing orders to replenish stock is entered with sources, deliveries, prices, etc.

Miscellaneous Stores.—Under the designation of miscellaneous stores are the following kinds of items:

1. Parts or materials to be temporarily stored for current work.
2. Parts ordered for special jobs and not used, either because left over or replaced by other items.
3. Materials ordered for special jobs but not used.
4. Repair or replacement parts on old models or obsolete models of the company's products, for which orders are only infrequently received.
5. Items or materials no longer used on current products and for which there is no demand.
6. Parts from miscellaneous dismantled products or equipment which may be considered usable for certain purposes around the plant.
7. Maintenance parts and items little used or no longer used.

Such items are usually kept in separate bins in the regular storage locations to prevent them from becoming mixed with, or issued in place of, the items regularly carried, to make room for regular items, and to simplify stores issuing. They may possibly be used, however, from time to time and hence are kept in the storeroom and entered on the stores records so that their existence will be known and they will be available if wanted. Since they are not regularly issued and stocks are not replenished, it is necessary only to sort them into groups, put them in a suitable place, and record them on simple records, of standard size but specially printed, filed in a separate section of the regular stores record system. Bin tags or identification tickets should be placed with them in the storeroom.

The cards or sheets used require usually only the following information:

Heading:
1. Material or part name.
2. Symbol.
3. Specification or description.
4. Original source, such as purchase requisition and order number.
5. Date originally entered in records.
6. Use—for what purpose, on what product or equipment, or for what department.
7. Any restrictions on use or issue.
8. Location in storeroom.
9. Unit of issue.

Columns for entries:
1. Date of any transactions.
2. Order number (issue, purchase, manufacture).

3. Quantity.
   a. Received.
   b. Issued.
   c. Balance.
4. Unit price.
5. Total value.
6. Reason or circumstance of issue, or department or person requisitioning.

Certain of the above data are historical but will be of service in settling any questions of demand, disposal, etc.

Other Forms.—Other forms used in some cases are a **materials shortage slip,** when materials are not apportioned and are not on hand or there are not enough on hand to fill the order completely; a **notice of danger point,** which is sent along when materials fall to a very low point because of delays in arrival of shipments; an **order to stock material,** sent to stores records when a new material is to be stocked; a **verification slip,** sent by the stores record clerk to the storeskeeper to verify the quantity on the stores records with the bin tag record; or a **stores count report,** used to enter a physical count made in the storeroom, which will be sent to stores records and to the accounting department to adjust differences between the records and accounts and the actual quantities on hand.

ENTRY INTO COST AND ACCOUNTING RECORDS.—Materials issue and stores credit slips are sorted in the stores record section by classes or groups in the manner in which the accounts are kept, and posted and priced. Summary sheets of each classification are also posted. The slips are then sent to the cost accounting department for financial control purposes. The totals from these data are credited to the accounts. Receiving reports are similarly classified and charged to the accounts. Tabulated reports submitted to the cost accounting department by the stores record section should agree with these records. Discrepancies between stores records and stores counts must likewise be posted as adjustments to obtain agreement.

The stores requisitions are sorted by classes of products or by job numbers, and overhead expense accounts, in accordance with the way costs are set up. They are then entered on the cost records, together with direct labor costs from time tickets, and, by the addition of proper overhead costs, give the manufacturing costs of products or specific jobs, for purposes of checking with estimates or previous records, or for study if on new kinds of work, so that plans for holding costs within limits, or reducing them, can be applied. Under a standard cost plan, of course, procedures are simplified by the use of the predetermined cost of each item.

COURSE OF THE MATERIALS ISSUING, APPORTIONING, AND ENTRY PROCEDURES.—The course of a materials requisition slip, the activities it is associated with, and the entries that are made from it are better understood from Fig. 25, developed by John R. Bangs.

1. A materials requisition is written in the planning department from the bill of materials for a production order which authorizes the manufacture of a product and the withdrawal of the necessary parts and materials from stores.

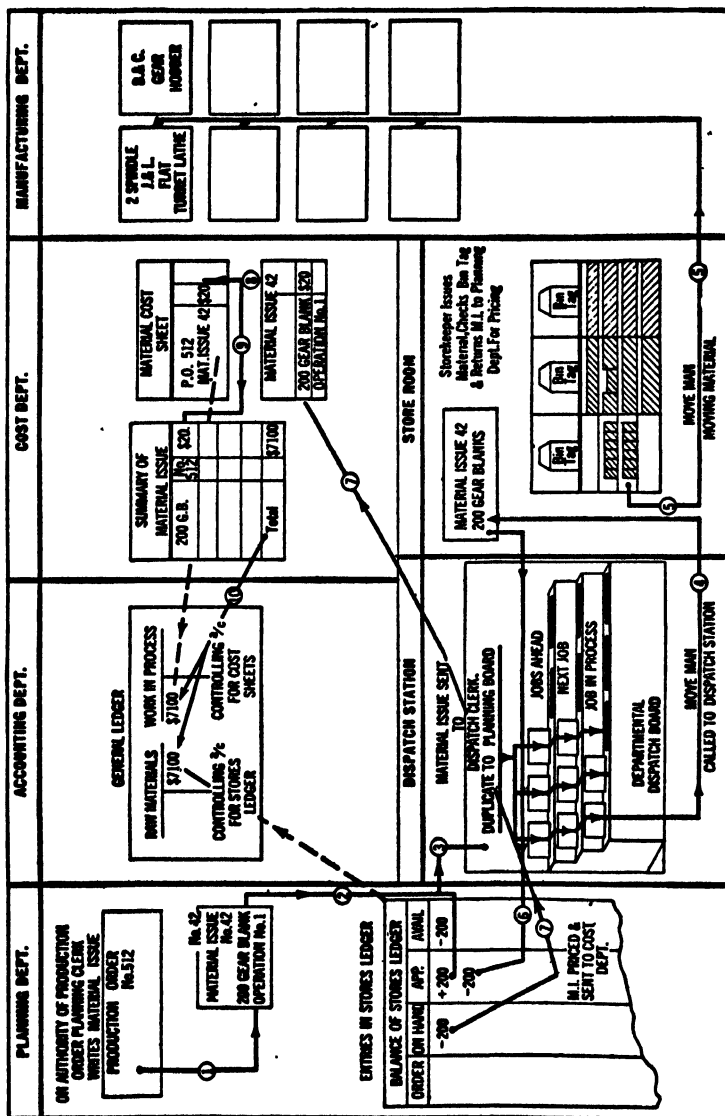



FIG. 25. Fundamental Procedures in Issuing Stores

2. This materials issue slip is sent to the stores record or balance-of-stores clerk for addition to the apportioned column and consequent subtraction from the available column on the sheet for the parts shown, gear blanks. (Note that balances and quantities are not shown in the diagram, only the transactions on this materials issue slip.)
3. After it is apportioned, the materials issue slip goes to the shop dispatcher in the gear manufacturing department, who files it and posts the corresponding work order in the control board pocket or other place for keeping data for the machine on which the work is done.
4. When this job is about to be started, the dispatcher takes out the materials issue slip and sends it with a move man to the storeroom.
5. Here the storeskeeper issues the material, which the move man takes to the gear manufacturing department.
6. The storeskeeper, after posting the issue to the bin tag, sends the materials issue slip back to the balance-of-stores clerk who subtracts it from both the apportioned and on-hand columns of the sheet for the gear blanks. At the same time he enters the unit cost of the gear blanks on the materials issue slip and calculates the value of the issue.
7. The materials issue slip is forwarded to the cost department for posting.
8. It is entered in the materials cost sheet for the particular production order.
9. It is also posted to the summary of material issues for the period, which is later totaled.
10. The summary sheet is later sent to the accounting department and posted as a credit to the raw materials account and a debit to the work-in-process account. The debit postings must agree with the total of material issues for jobs in the shop, while the credit postings must agree with the balance of stores postings of withdrawals from stores.

Raw materials and parts or subassemblies which are stored are all handled in the manner described. Shipping orders for the withdrawal of finished products from stock for delivery to customers are handled according to a similar plan.

REPLENISHMENT OF STORES.—Stores are replenished (1) by the writing of purchase requisitions which are sent to the purchasing agent as the basis for purchase orders, and (2) by the writing of manufacturing requisitions which are sent to the planning section of the production control department as the basis for putting through manufacturing orders for items to be made within the company's own factory from materials withdrawn upon requisition from the storeroom. As has been stated, the stores record clerk writes these purchase and manufacturing requisitions. Where there is no planning department, he sends the manufacturing requisitions usually to the plant operating superintendent. The basis for each requisition under the maximum-minimum plan is the reorder point on the stores record, and the quantity requested is the order quantity there stated, both of which are changed as the rate of use of an item shows definite trends up or down over a period of time. The stores record clerk usually is kept posted on any changes contemplated on items carried—quantity increases or decreases, dropping items, adding items—but may himself ask regarding changes in reorder points or reorder quantities as he notes variations in consumption on the records.

Determining Economic Lot Sizes and Inventory Quantities

CONTROL OF QUANTITIES.—In a company manufacturing to customer's order, or when the product is manufactured to a definite schedule calling for a certain number of each finished article within a given time, the quantity control of direct materials is almost mathematically automatic. On what might be called standardized articles manufactured in varying quantities over a given time, control is not so simple although the types of materials are standardized. When the products are nonstandardized, control is more difficult. Nevertheless, under any form of manufacturing and regardless of types of products, the quantities of materials maintained in inventory should be held at that point which permits "the greatest amount of business possible with the least amount of capital invested per unit of product . . . over a given period" (Cartmell, Stores and Materials Control).

While fixing maximum and minimum quantities as the limiting factors will serve in low-volume production in small plants, sometimes in a more adequate control practice five important quantity standards are used:

1. **The maximum.** The upper limit of the inventory.
2. **The minimum.** The lower limit of the inventory. In reality, it is the "cushion" stock or margin of safety to be used only in case of emergency. Except when requirements have been abnormal, it is intended that there should always be at least this quantity on hand.
3. **The reordering point.** The reordering point represents the sum of the "cushion" stock and the quantity required for use during the interval between placing an order and its delivery. When the available balance on hand and on order falls to this level, it is the signal that a new order must be placed.
4. **The danger point.** This quantity has gone below the minimum safe limit of the inventory. When the quantity on hand falls to the danger point, emergency action is necessary for effecting delivery of the replenishment stock without delay. The method for signaling this point is illustrated in Fig. 21.
5. **The standard ordering quantity.** The standard quantity to be purchased or manufactured at any one time. It constitutes the economic quantity if properly determined. Repeat orders for a given part or material are tentatively for this amount.

An illustration will serve to indicate more clearly the use of these standards. A company in one of its manufacturing operations uses steel bars 2½ in. in diameter and 10 ft. long, which are purchased from time to time as required. The average daily requirement for this material is 10 pieces. The time required to secure delivery after placing an order is 30 days. An examination of the company's records shows that the maximum requirement for any 30-day period will not exceed 450 pieces; also that the minimum requirement during any such period is not likely to fall below 100 units.

The maximum and minimum method of inventory control is used by this company and the standards for this material are:

Maximum	1,350 units
Minimum	150 units
Standard order	1,000 units
Ordering point	450 units

The above ordering point is easily determined, for evidently it need not be greater than is required by maximum conditions during the time

when the replacement order is outstanding. This quantity, by assumption, is 450 units.

By definition, the minimum or "cushion" stores is determined as follows:

Ordering point	450 units
Less: Average requirements during time required to fill an order—Average daily requirements (10 units) × Days required to fill an order (30 days)	300 units
Minimum	150 units

The maximum, on the other hand, is determined as follows:

Ordering point	450 units
Less: Minimum consumption while an order is being filled	100 units
Maximum balance on hand when new supply is received	350 units
Add: Amount to be received on the standard order	1,000 units
Maximum	1,350 units

STANDARD PURCHASE ORDER QUANTITY.—In the foregoing illustration nothing has been mentioned as to how the standard order of 1,000 units was determined. The ordering point and the minimum are entirely dependent upon (1) time required to fill an order, (2) probable variations in the rate of consumption within the plant. Both of these conditions can usually be predicted with a reasonable degree of accuracy. The maximum, on the other hand, cannot be determined until the standard order is known, and it is upon the latter that the economy of the inventory investment depends. An increase in the size of the order makes it possible to order less frequently, thereby effecting some purchasing economies. But this is not all. Large orders mean larger average inventories, and the point may soon be reached where purchasing economies are counterbalanced by the expense of carrying the excess supply.

The problem is very similar in the case of parts made in the plant and stored for future use, although the detailed elements of cost are those for manufacturing instead of purchasing.

The **economical order** is that which can be secured at the least overall unit cost, but it is necessary to be sure that all costs have been included. To state it concretely, if a company uses steel bars, it is not so much a question of placing each order for the quantity for which the vendor quotes the lowest purchase price, as it is of securing an uninterrupted supply of the commodity at the least ultimate cost. It is the over-all cost of the material when issued to the production department, rather than price quotations, which determines the effectiveness of purchasing and inventory control. The same considerations apply to manufactured items.

Many factors may exert an influence upon ultimate costs. Those which usually are of most importance are:

1. Physical deterioration of the commodity while held in storage.
2. Obsolescence.
3. Seasonal fluctuations in the price of the commodity.

4. Seasonal fluctuations in the availability of the commodity.
5. The necessity for adequate inventory storage facilities.
6. The cost of purchasing, including all other clerical costs in receiving, accounting, etc.
7. The advantage of bargaining for large versus small quantities.
8. The importance of the investment involved.

The effect of all these factors may be reduced to a fairly definite schedule of costs which may be classified as follows:

1. Costs which tend to decrease as the size of the order is increased:
   a. Purchase price.
   b. Cost of purchasing.
2. Costs which tend to increase as the size of the order is increased:
   a. Inventory storage charges, covering rent of space and expense of light, heat, janitor service, etc.
   b. Inventory carrying charges, including interest on investment, insurance, risks of spoilage, obsolescence, etc.

Purchase Price.—The possibility of securing advantageous terms by buying in large quantities, which is commonly recognized, is likely to be important in determining the size of the standard order.

Cost of Purchasing.—The computing of the unit cost of purchase orders is a problem in cost accounting, and methods used for securing average unit commodity costs may be applied here as well. The average cost of handling a purchase order may be easily computed, of course, by compiling the cost of purchasing, receiving, accounting, etc., for a given period and dividing this cost by the number of orders negotiated during the period. Purchase orders may be classified as to type and total costs may be allocated to groups. From these figures, in turn, average order costs within each group are easily determined and are sufficiently accurate.

Unit Storage Costs.—Parts or materials storage costs may be computed by allocating all the costs of operating the storerooms to the items stored in proportion to the space occupied or upon some other reasonable basis.

Inventory Carrying Charges.—Cartmell (Stores and Materials Control) says:

> Carrying charges for all materials in stock, which charges include insurance, taxes, depreciation, rent, and manual and clerical labor, plus the interest to be earned on the investment probably amount to from 10% to 20% per annum of the value of the stores. . . .
>
> If the inventory of certain materials is allowed to increase or even to remain stationary, there is also the possibility that the material will suffer damage or will deteriorate to a value far under its cost; or it may become entirely obsolete and not usable for the purpose for which procured. There is also the possibility of the market falling in price at the very time the stocks are at their highest, and the true value of whatever is on hand is decreased accordingly. Hence, the management in deciding upon the maximum quantity must give some thought to carrying costs and the chances of loss of stock. Charges increase proportionately with the quantity stored, and the length of time the item is in stock, and may quickly overcome the advantages of buying or of manufacturing solely for the sake of a low unit price. An accurate estimate, however, can easily be made and should always be made when considering the carrying of materials in stores. This estimate should be figured as a per cent of the value of the material.

According to Parrish, for stores or stocks in an industrial concern, a charge of 25% per annum of the cost of the inventory is considered reasonable on active items (Alford, Principles of Industrial Management). As compared with other estimates, the total of 25% in this summarization appears to meet with agreement, but the percentage for storage facilities seems rather low and those for other factors—notably obsolescence—seems to be high (see Mitchell example, later).

Item	Per Cent
Storage facilities	.25
Insurance	.25
Taxes	.50
Transportation	.50
Handling and distribution	2.50
Depreciation	5.00
Interest	6.00
Obsolescence	10.00
Total	25.00

INVENTORY COST COMPUTATIONS FOR VARYING SIZES OF ORDERS.—Mitchell (Purchasing) has this to say: "The use of the cost standards, in determining the economical order, can be illustrated by a concrete case. The following information is available as to the requirements and purchasing conditions of commodity X:

1. Total annual requirements—5,000 units.
2. Average daily requirement—16 units.
3. Estimated time required for securing delivery after the placement of an order—30 days.
4. Estimated maximum requirements during any 30-day period—680 units.
5. Estimated minimum requirements during any 30-day period—100 units.
6. Estimated cost of handling a purchase order—$5.
7. Estimated storage cost for average inventory—30 cents per unit, per annum.
8. Estimated carrying charges for the average inventory, including interest on the investment, insurance, risk of damage, etc.—10% of the average annual inventory valuation.

"In addition the purchasing department has prepared an estimate of the probable unit purchase price, depending upon the size of the order placed. This schedule is shown in columns 1 and 2 of Fig. 26.

"From information available, the data appearing in columns 3, 4, and 5 can be computed. The estimated unit buying expense in column 3 is

1 Size of Order	2 Est. Unit Price	3 Est. Unit Buying Expense	4 Average Inventory in Units	5 Est. Value of Average Inventory
100	$2.20	$ 05	250	$ 550 00
200	2.10	.025	300	630.00
500	2.05	.01	450	922.50
800	2.00	.0062	600	1,200.00
1,000	1.95	.005	700	1,365.00
1,500	1.93	.0033	950	1,833.50
2,000	1.92	.0025	1,200	2,304.00

FIG. 26. Data for Inventory Computation

obtained by dividing the cost of handling a single order, that is, $5, by the number of units included in an order as shown by column 1. The average inventory, as shown in column 4, is computed by the formula:

$$\text{Average inventory} = \frac{\text{Standard order}}{2} + \text{Minimum}$$

"The minimum is computed according to the method previously explained, as follows:

Ordering point, which by definition is the maximum requirements during the period required to fill an order, including the "cushion" stores which might have to be drawn upon in case of emergency		680 units
Less: Average requirements during the time required to fill an order:		
Average daily requirements	16 units	
Time required to fill an order	30 days	480 units
Minimum or "cushion" stores		200 units

CALCULATION OF ECONOMICAL ORDER.—". . . cost of the year's supply of commodity X and effect of variation in the size of purchase order can now be computed. The results are shown in Fig. 27. From this figure it will be noted that the economical order is approximately 1,000 units. This condition being true, the quantity standards for commodity X are as follows:

Minimum	200 units
Ordering point	680 units
Standard order	1,000 units
Maximum	1,580 units"

Trial Ordering Quantity	100	200	500	800	1,000	1,500	2,000
Purchase Cost: Total year's requirements × Corresponding unit price (5,000 × Corresponding price appearing in column 2, Fig. 26).	11,000	10,500	10,250	10,000	9,750	9,650	9,600
Buying Expense: Total year's requirements × Corresponding unit buying expense (5,000 × Corresponding unit appearing in column 3)	250	125	50	31	25	17	12
Cost of Storage: Average inventory × Unit storage cost (Column 4 × 30 cents, unit storage cost)	75	90	135	180	210	285	360
Inventory Carrying Charges: Average inventory valuation estimated percentage (Column 5 × 10%, estimated rate)	55	63	92	120	136	183	230
Totals	11,380	10,778	10,527	10,331	10,121	10,135	10,202

FIG. 27. Inventory Cost Computations for Orders of Varying Sizes

The above method covers the standard purchase order quantity. Determination of a standard manufacturing quantity involves practically the same considerations. In calculating the latter quantity, the variable element corresponding to the reduced purchase price realized by large quantities, is the reduced set-up cost per unit realized by increasing the number of pieces per lot. Also, the cost of issuing production orders and all other associated clerical and accounting costs should be substituted for the cost of purchasing and its associated costs.

An example of a calculation to determine the economic quantity for a part that is to be manufactured in the plant and will be stored is given herewith (Alford, Principles of Industrial Management):

Assume these data:

Preparation cost, $15.
Storage charges per piece per year, $.001.
Manufacturing cost per piece, $.25.
Desired annual return on capital, 10%.
Manufacturing capacity per year, 1,000,000.
Demand for pieces per year, 960,000.

Further data for the computation are arranged in Fig. 28. Quantities studied range from one lot to seven lots per year; the corresponding sizes of the lots range from 960,000 to 137,000. This table also gives the maximum inventory in pieces, computed from a production per week of

Number of lots per year	1	2	3	4	5	6	7
Number of pieces per lot	960,000	480,000	320,000	240,000	192,000	160,000	137,000
Maximum inventory in pieces	38,400	19,200	12,800	9,600	7,680	6,400	5,600
Maximum investment in inventory	$9,600	$4,800	$3,200	$2,400	$1,920	$1,600	$1,400

FIG. 28. Data for Computation of Economic Manufacturing Quantity

Number of lots per year	1	2	3	4	5	6	7
Preparation cost per year $15 × No. of lots	$15.00	$30.00	$45.00	$60.00	$75.00	$90.00	$105.00
Storage cost per year. One-half the maximum number in inventory	19.20	9.60	6.40	4.80	3.80	3.20	2.80
Interest charge per year. One-half investment in inventory × .10	480.00	240.00	160.00	120.00	96.00	80.00	70.00
	$514.20	$279.60	$211.40	$184.80	$174.80	$173.20	$177.80

FIG. 29. Cost Comparisons for Manufacturing Quantities of Various Sizes

20,000 pieces, and a demand per week of 19,200 pieces. The difference, 800 pieces, is carried to inventory for each of 48 weeks, the time required to make 960,000 pieces when one lot is made per year, giving a maximum inventory of 38,400 pieces. The investment in inventory is the number of pieces multiplied by the manufacturing cost per piece.

Fig. 29 gives the costs that vary with the size of manufacturing lot, these being the preparation and storage costs, and the interest on the investment in inventory. Examination shows that the lowest annual cost for the sum of these three charges is when six lots are made per year. However, there is no practical difference in the costs for five, six. and seven lots per year, showing that there is a considerable range for the economic number of pieces per lot.

Calculation of standard quantities by analytic means, as described above, takes considerable time and the method is not widely used. Formulas have been devised, therefore, to make quicker calculations and examples of these formulas and their application follow. There is not close agreement between the results from the analytic method and the formulas. Both should be used wherever convenient as a means of either checking on quantities which have been selected tentatively by judgment and experience, to see whether the selection seems correct, or, conversely, to make a calculation and then judge or modify it in the light of experience and reason. Many authorities do not favor the use of such methods, but they are presented here because of their availability at least as checks.

NORTON FORMULA.—Paul T. Norton, Jr. has devised the following method involving the equation given below. His symbolization is:

Q = Economic lot size (pieces per lot)
S = Total preparation cost per lot in dollars. (Included is the cost of preparing manufacturing orders, setting up machines, and other costs that are independent of the number of pieces in the lot.)
A = Cost of storing one piece for one year, in dollars
B = Annual charges for taxes, insurance, etc., in per cent of the inventory investment, used as a decimal
C = Manufacturing cost per piece in dollars. (Included are costs of material, direct labor, and overhead.)
I = Desired annual return on capital in per cent, used as a decimal
N = Number of days worked per year
P = Number of pieces manufactured per day
U = Number of pieces used (or shipped) per day

Then,

$$Q = \sqrt{\frac{S}{\dfrac{(B + I)C + 2A\left(1 - \dfrac{U}{P}\right)}{2NU}}}$$

Example. A worked out example shows how the formula is used, and the difference is the result obtained when the rate for the desired return on capital is used, instead of the rate for simple interest.

Assume the following data:

$S = \$10$ $\quad I = 20\%$
$A = \$.001$ $\quad N = 300$
$B = 3\%$ $\quad P = 1{,}000$
$C = \$.10$ $\quad U = 100$

Substituting in the formula,

$$Q = \sqrt{\frac{10}{\frac{(.03 + .20) \times .1 + 2(.001)\left(1 - \frac{100}{1{,}000}\right)}{2(300)\ (100)}}}$$

$$= \sqrt{\frac{10}{\frac{.0248}{60{,}000}}} = \sqrt{\frac{10}{.41\ (10^{-6})}} = 4{,}940 \text{ pieces}$$

If a simple interest rate of 6% were used as the value of I, the answer would be:

$$Q = \sqrt{\frac{10}{.16\ (10^{-6})}} = 7{,}900 \text{ pieces}$$

DAVIS FORMULA.—The Davis formula for economic manufacturing lot sizes is built up from the following factors symbolized as indicated (Davis, Purchasing and Storing):

Q = The quantity to be manufactured in a single run that will give the lowest unit cost
A = The preparation cost of manufacturing, expressed in dollars
M = The equivalent annual rate of manufacturing, expressed in the same units as Q
S = The equivalent annual rate of consumption, expressed in the same units as Q
C' = The standard cost of the particular item, expressed in dollars per piece.
Z = The desired rate of profit on working capital, expressed in per cent and used as a decimal value
B = The number of square feet of net storage space required to store one unit of the item
E = The annual unit charge for storage space, expressed in dollars per square foot of storage space
k = The lot factor, expressing the influence of lot or batch production on the economy of manufacturing, $k = 2F - 1$, approximately
F = The ratio R/R_1 or the ratio of quantity at order point to quantity used while awaiting delivery

$$Q = \sqrt{\frac{2\,AMS}{(M + kS)\,(C'Z + 2BE)}}$$

The following example illustrates the use of the Davis formula:

Example. Using the same values as in the Norton equation and assuming that the ratio of R/R_1, reorder point to consumption while getting the new stock into the storeroom, is 1.1, that is 10% of the "consumption while replenishing" is assumed to be sufficient as a cushion stock, the following figures apply, in determining the economic manufacturing lot:

$A = \$10$, preparation cost
$M = 300 \times 1{,}000$, equivalent annual rate of manufacture
$S = 300 \times 100$, equivalent annual rate of consumption
$C' = \$.10$, standard cost per piece
$Z = 20\%$, rate of profit on working capital
$B \times E = \$.001$, sq. ft. storage space per unit $\times$ annual storage cost per sq. ft.
$k = 2F - 1 = 2 \times \frac{R}{R_1} - 1 = 2 \times 1.1 - 1 = 2.2 - 1 = 1.2$, the lot factor

$$Q = \sqrt{\frac{2 \times 10 \times 300{,}000 \times 30{,}000}{(300{,}000 + 1.2 \times 30{,}000)(.10 \times .20 + 2 \times .001)}}$$

$$= \sqrt{\frac{20 \times 300{,}000 \times 30{,}000}{30{,}000\ (10 + 1.2)(.02 + .002)}}$$

$$= \sqrt{\frac{6{,}000{,}000}{11.2 \times .022}} = 4{,}515 \text{ parts in the economic manufacturing lot}$$

The difference in results between the two formulas is caused by the basis of certain of the assumptions; for example, the ratio of reorder point to cushion stock.

Buying in advance of need in the hope of a profit through rising prices, tempers the buying policies of many companies. Studies indicate that experience of one important converter of a basic commodity is typical, and is commented on by Cartmell as follows (N.A.C.A. Yearbook, 1938):

> The actual costs of the materials used during the last 15 years were compared with what the costs would have been if each month's needs had been purchased during the preceding month at the average market price. The study indicated that under the month-to-month plan the buyer would have saved a very large sum of money, equal to several per cent of the actual costs. The forward buying policy did not pay even without considering the carrying costs of the inventories, which may have been another 2% of the total actual costs. I have seen only one similar study covering recent years which showed the opposite result. While in some years many businesses can show a nice profit from a forward buying policy, they seldom do over the long term, especially where the carrying costs of inventories are concerned.

THE MATERIALS BUDGET AND INVENTORY TURNOVER.—Proper investment in inventories under varying manufacturing conditions is of vital importance. A materials budget should be established for each class of materials as a part of company's financial budget. This step is necessary not only as a plan for guidance of those who are deciding the quantities of materials to be maintained in inventory, but also for checking actual conditions. Each class may be subdivided as may be advisable.

Inventory turnover, the number of times inventory is used within a given period, is a convenient measure of the efficiency of materials control and utilization of materials. Different industries have radically different turnovers but the rate in any given industry is usually some-

what uniform, depending as it does upon its particular operating and distributive processes. The method of computing the turnover is to divide the inventory into the usage, that is, the value of all materials consumed over a period, say a year, divided by the value of the average inventory on hand during the period. The calculation may be applied to include only productive or direct materials and separately for indirect materials, or to the sum of both.

In manufacturing industries, turnover of inventories should be figured for the business as a whole, for the several departments or units, and for each class of inventory—raw materials, work in process, finished stocks, and supplies. Turnover of **raw materials** should be based on the average raw materials inventory and the amount that has gone into process; the turnover of **work-in-process** inventory, on the average work-in-process inventories and value of products completed during the period as represented by credits to work-in-process accounts; turnover of **finished goods,** on average inventory of finished goods at cost and cost of sales; and turnover of **supply inventories,** on average investment in supply stocks and amount of supply expenses for the period.

Frequent review of quantities carried is highly important and should be done by an organized analytical procedure. Quantities carried can sometimes be cut, especially in the case of slow-moving materials, and obsolete materials can be disposed of. Methods for checking on inventory turnover have already been discussed.

Standardization of Materials

STANDARDIZATION AND SIMPLIFICATION.—The need for standardization of products and materials needs no demonstration. As a basis for standardization, a program of simplification is necessary. Simplification consists in eliminating the needless or little used varieties, types, sizes, styles, shapes, and other irregularities and consolidating on as few varieties as possible, so that stores space and records may be cleared of the unnecessarily different items which may have been kept on hand.

Those which are retained then are studied as to uses, improvements which can be made in their application, interchanges possible under certain conditions, substitutes which may be obtained when the materials are not readily procured, quantities to be carried for manufacturing needs, etc. In this manner the entire manufacturing program may be improved and many other advantages obtained. Supplies likewise should undergo the same study. From the standpoint of efficient maintenance, many companies also tend to standardize on the equipment purchased and used. Not only are labor costs reduced by equipment standardization, but also the stocks of maintenance parts and supplies kept are considerably cut down without interfering with operations.

ORGANIZATION FOR STANDARDIZATION.—Programs of materials standardization will not work unless placed under effective organization and administration, with power for action properly allocated and exercised. There is no one logical place in an organization where standardization should invariably be located, because the work involved and its results affect many departments—sales, engineering, purchasing,

production control, manufacturing, storing, accounting, and others. Responsibility for control is usually centered in the department where the question is most important or fundamental, or where action can or will be taken, and often the whole plan is better handled by a representative committee from all departments concerned, but this committee must have a chairman preferably connected with production control and must report to some executive. Materials standardization also may be part of the work of a general plant standards committee.

Materials standardization and simplification thus may be centralized in one of the following departments or may report to one of the designated individuals:

Department	Individual
Engineering	Chief product engineer, standards engineer.
Production Control	Superintendent of production control, materials standards engineer.
Purchasing	Purchasing agent.
Stores	Chief storeskeeper.
Manufacturing	Works manager, standards engineer.
Inspection	Chief inspector.
Accounting	Controller, cost accountant, where these men have supervision of inventory.
Sales (rarely)	Sales manager, where product standardization is influenced very directly by the sales department and sales engineers are employed.
Materials Division	Materials manager, but such a division is not often set up.

Where a materials standards committee is set up, it perhaps most frequently reports to the works manager, next to the production control supervisor or chief engineer, sometimes to chief inspector or the purchasing agent, and much less frequently to any of the others.

The committee should include representatives of most, or all, of the departments listed above, for purposes of coordination, to get quick advice or reactions or proposals, to carry on specific studies on certain phases of the work, to adapt plans better to the all-round needs of the plant, and to sell the idea and get cooperation from the different departments. For best results perhaps three of the key men should act as a sort of executive committee, having the others associated but not burdened with major responsibilities or details. Usually such committees carry on the work as need arises or suggestions are submitted. Where a definite, continuous program is carried on, a materials engineer, with the necessary staff, should be appointed to direct it but he may receive the aid of, and carry on many of his applications through the assistance of, members of a materials standards committee.

In many cases, the materials standards committee may not only handle the work of standardization, but may also carry on the reviews of inventories at reorder points, mentioned in a previous part of this Section, and may likewise recommend changes in classifications, specifications, ordering points, ordering quantities, and other factors.

PROCEDURE IN STANDARDIZING MATERIALS.—The procedures found most successful in any program of standardizing materials have been stated by Davis (Purchasing and Storing) as follows:

1. A complete list of items regularly carried in stores must be obtained. Often, the lists obtained by the last annual inventory are a satisfactory beginning. The records of the purchasing department, also, will aid in the preparation of such a list.
2. These items should be classified by kind or use. As far as possible, the existing stores grouping should be used for economy. The basic stores grouping probably will conform to the general accounting classification of accounts. However, it is often found that the one existing has not been worked out to facilitate the operating control of inventories. As a result, some changes usually are necessary.
3. The uses to which each item is put should be determined. It is often found that different materials are used for the same or similar purposes in different departments. Here, obviously, is an opportunity for simplification.
4. The materials in the same classification should be compared to determine those having similar characteristics. It may be found that certain materials, used for different purposes, are similar. For instance, two kinds of steel may be similar in tensile strength, ductility, and other characteristics. It may be possible to eliminate one of them, and use the other for all purposes formerly served by both.
5. Possible substitutes for standard materials should be determined. In the above case, the kind of steel that was eliminated may be listed as a possible substitute for the other. Sometimes the purchasing department is unable to procure the standard material without too great delay or too great purchase cost. In such cases it is desirable for production engineers to have reasonable leeway. Substitutions for standard materials, however, should not be permitted without the approval of some higher authority.
6. On the basis of the above considerations, a revision of the standard list of classified stores is made. Such lists are important for control of inventories. Requisitions for items not included in the lists will not be honored, unless approved by higher authority. Usually each department and storeroom is further restricted to a list of items within the classified list.
7. For each item that is retained in the classified list, the qualities that it should possess to meet the purposes for which it is to be used should be determined. These qualities are recorded permanently in the form of specifications for the use of the purchasing, receiving, and other departments that need them.
8. To facilitate the work of ordering, requisitioning, accounting, etc., a material symbol system should be worked out, and a distinctive symbol assigned to each item in the classified list.
9. Finally, there should be some organization for controlling and enforcing observance of the standards. This may be a materials committee. Such a committee would pass on the inclusion of new items in the classified list, and similar problems.

MATERIALS SPECIFICATIONS.—Materials may be designated or specified in a number of ways and from a variety of sources:

1. Common trade names.
2. By manufacturer or source.
3. Brand names.
4. Manufacturers' specifications.
5. Trade specifications.
6. Engineering or technical association or agency.
7. Laboratory specifications (consulting or commercial groups).
8. Government specifications.
9. By the user company through its own research.

The common ways in which specifications for materials, parts, or supplies may be given or expressed are by:

1. Nomenclature: use of specific terms or indicators, such as the common symbols, codes, manufacturers' catalog symbols, product symbols, or trade names or designations.
2. Descriptions.
3. Dimensions and proportions.
4. Quality or composition.
5. Ratings or performance.
6. Methods of analysis or test.
7. Specific requirements, as for safety.

Specifications, when set, must define, delimit, state, or clearly indicate the characteristics required so that the materials or component parts covered will be:

1. Suitable for the product from the standpoint of dimensions, physical and chemical properties, etc. (engineering), and from the viewpoint of the customer (sales).
2. Conformable to technical requirements (engineering inspection).
3. Obtainable or produced with minimum difficulty (purchasing, manufacturing).
4. Convenient to handle, store, and issue (storing).
5. Workable, if possible, without unduly special provisions (production control, manufacturing).
6. Standard to whatever extent feasible (engineering, purchasing, production control, manufacturing, inspection, storing).
7. Replaceable by substitutes if temporarily difficult to obtain (engineering, purchasing, production control, manufacturing).
8. Low in cost (purchasing, production control, manufacturing).

Development of Specifications.—In most cases specifications for materials and component parts will be adopted or developed by the engineering department or plant manufacturing research or control laboratory. Sometimes they may be prepared or formulated by a specialist or someone in the plant acquainted with their uses and applications. These specifications are conveyed to the other departments by means of drawings, bills of material, reference to standard specifications or special specification write-ups. Occasionally a materials standards committee will have something to say in regard to specifications but more often the specifications will be merely referred to such a committee for consideration as to their effect on purchasing, production control, manufacturing, and inspection, and in the attempt to fit them into any simplification and standardization program in effect. If some material already in use can be employed instead of a special kind, or if some other single variety can be adopted for both old and new uses, the inventory problem is aided.

Adequate attention to specifications, and standardization on sizes and varieties of items called for or carried, to eliminate the odd and the little used, are of decided benefit in manufacturing and production control. The plant frequently will be well equipped with machines, fixtures, tools, and equipment to handle certain kinds and sizes of material, and any work within this range is perfectly acceptable. The production control department will have operation lists, route sheets, tooling set-ups, time studies, instruction cards, wage rates, machine outputs, and stores controls established for such materials. Specifications will be

familiar to those using these materials. If, now, new specifications are introduced with reason and with the opportunity to cut costs or bring about further standardization, there is justification for making the substitution. If materials of another specification are introduced without some such definite engineering, operating, or economic advantage that outweighs the time, trouble, cost, and possible temporary upset of making the change, there has been a loss instead of a gain.

The sources of formulated specifications are much the same as those for standards because specifications are developed with the idea of having them become standards. Among the many agencies and sources are:

American Standards Association
Underwriters' Laboratories
Federal Bureau of Specifications
Bureau of Standards
American Society for Testing Materials
American Institute of Electrical Engineers
American Society of Mechanical Engineers
Society of Automotive Engineers

Specifications for materials, parts, or products which have been standardized can be obtained from the agency, laboratory, technical society, trade association, government body or manufacturer developing them. Most manufacturing companies try to use materials, parts, etc., which have been standardized and for which specifications exist, in their products, and develop specifications for only the items for which no market product will do, so that something special has to be made.

Items Covered by Specifications.—Specifications written within a plant must be carefully written and then reviewed by all departments concerned, or by an executive or engineer thoroughly familiar with the matter. Information of the following nature must usually be given:

1. Name of item.
2. Symbol or number.
3. Class or kind (if any).
4. Description, sizes, etc.
5. Uses or applications.
6. Material made from (if a part, product, or compound).
7. Methods of manufacture (if important).
8. Physical and chemical properties (if any).
9. Other standard requirements.
10. Tests or inspections to be applied or met.
11. Finish.
12. Method of packing for shipment.
13. Acceptance inspection by purchaser.

Copies of specifications should be prepared in whatever form convenient, some duplication process being preferable to typing, with carbons. The engineering, production control, purchasing, receiving, and materials standards committee would be most concerned. In many cases copies are also needed for bidders and vendors. Whenever changes in parts or materials specifications are to be made, a regular change order should be put through and copies should be sent to all of the above departments which should know of the changes. If there is a materials committee, it should pass upon the changes before they are put into effect, to prevent a departure from standards and the accumulation of unnecessary varieties of the same item.

NATIONAL AND INTERNATIONAL STANDARDIZATION AND SIMPLIFICATION.—Each leading country has its standards association for the purpose of national standardization and the development of the necessary specifications, and there has been cooperation among such agencies. The most active agency in national simplification, to reduce varieties, types, sizes, styles, etc., has been the Division of Simplified Practice, Bureau of Standards, U. S. Department of Commerce, which carries on its work on a basis of voluntary development of, and agreement upon, simplification programs for respective industries, through the cooperation and preponderantly major vote (80% or more) of the authorized representatives of users, retailers, dealers, manufacturers, technical societies, government agencies and the public concerned with introducing, and operating according to the terms of, the changes.

Physical Inventories

NEED FOR ACCURACY IN STORES RECORDS.—To be of the greatest service, stores records must be correct in both quantities and values. The records perhaps could be checked to the accuracy of a penny if need be, but reasonable accuracy is all that is required. While good work must be expected of record clerks, clerical errors may happen, and they are most likely to occur with records which require balances to be computed after each transaction. Records using cumulative totals are, therefore, sometimes preferable.

Discrepancies between quantities shown by stores records and those actually in stock are sometimes caused by errors of the storeroom. These errors occur through mistakes in descriptions and units of materials, wrong counts or weighing, and from issuing wrong materials and units. Some mistakes can be avoided by the use of proper symbols and standard descriptions so that the material is defined to all parties in the same terms.

TAKING INVENTORY.—An inventory or listing of all materials on hand should be made at least once each year. This stores inventory should be evaluated so that any discrepancies with the general ledger accounts may be adjusted. The inventory may be based upon a complete physical inventory (the physical counting or measurement of materials) or a book inventory (the listing of what the stores records show). The physical inventory plan means taking the count during a short period. The book inventory may be merely a summary of the unchecked records, but is much closer to accuracy if the continuous or perpetual inventory plan is followed under which throughout the year there has been a constant checking of individual counts and adjustments have been made to the stores records whenever any discrepancies between count and record have been caught.

If only one physical inventory is taken per year, it should occur at or near the end of the fiscal year, which time usually coincides with the yearly low point of production and of stores.

The advantages of a complete periodic physical inventory are:

1. A clean-up of the factory is made.
2. Work in process can be checked more accurately with operations at a standstill.
3. The shutdown usually permits making repairs and doing maintenance work otherwise impossible or impractical.

Such a method of inventorying, however, involves difficulties not experienced in connection with the continuous physical inventory.

A book inventory is not desirable unless the inventory records are kept in sufficient detail to present a complete picture of materials, and unless they are backed by continuous physical inventorying as noted above. Under this plan every item of stores should be checked by actual count at least once a year; three or four times is better. Important items may be checked monthly.

The continuous physical inventory of items in stores, which is the preferable method for all purposes, is carried on by the regular stores personnel during lulls in issuing activity, or on requests for a check by means of a verification slip or request for count of stores forwarded from the stores record section, or on a planned periodic program to cover the entire storeroom at least once a year and the more important items semi-annually, quarterly, monthly, or sometimes oftener, especially in emergencies. A stores count report would be sent by the storeskeeper to the stores record section, where any corrections necessary would be made in the stores record sheets or cards, after which these reports—noting any discrepancies—would be sent to the accounting department for periodic adjustments in the materials accounts. In a large organization the same plan may be followed, or continuous physical inventorying may be performed by one or more specially delegated persons who devote their entire time to this activity. Obviously, preparation for each step must be carefully planned but not as elaborately as for a complete physical inventory because the procedure is routine for the personnel involved. The principles are the same as those described below for the complete annual inventory.

The advantages of a continuous physical check under the perpetual inventory plan are:

1. The plant does not have to be shut down.
2. The count is not made under pressure, hence, is more accurate.
3. Records are kept more accurately when subject to continuous check.
4. Errors and irregularities are discovered and adjusted more quickly.

PREPARATION FOR INVENTORY.—The need of preparation for taking the annual physical inventory cannot be overemphasized. The larger the inventory, the more important the preparation. Complete written instructions should be prepared in ample time for all individuals to become familiar with the plan. These instructions should cover the following points:

1. Date of inventory and duration.
2. The personnel and their individual duties.
3. General procedures to follow in taking the inventory.
4. Classes of materials and special instructions concerning each.
5. Forms to be used and special instructions concerning them.
6. Methods of evaluation and tabulation.
7. Checking against stores records and adjusting discrepancies.

Some large concerns have complete inventory manuals, containing explicit instructions. Such manuals are advantageous in that procedures become standardized and consistent from year to year, except for modifications to suit current conditions. Thus the inventory personnel becomes more expert in carrying out the procedure.

Date of Inventory and Duration.—The date of the inventory should be as of the end of some month, to facilitate comparison with the financial records. Inventories usually take longer than one day but should be completed as rapidly as possible to shorten the shutdown of the plant, and to minimize the movement of materials if some of the inventory should be taken when plant is not idle.

The Personnel and Their Individual Duties.—The physical inventory, being fundamentally a financial check, is usually under the general supervision of a financial executive, preferably the controller. The general physical direction is usually under the factory or production manager. The detailed supervision is usually under each department head. The purchasing department should be instructed to verify and pass all invoices covering materials received up to the inventory date and to submit lists of all items in transit and of all materials received for which invoices were lacking at inventory date. All invoices in dispute should be adjusted and passed. The purchasing department should also furnish a record of all materials, patterns, tools, etc., in the possession of outside fabricators and obtain statements from them regarding such items. The accounting department should reconcile with the books all statements of accounts received from vendors, and adjust any differences. Lists of all materials billed prior to inventory date which are still awaiting shipment and of all goods out on consignment should be prepared. The department should see that all materials transactions and labor distributions are properly recorded to agree with the "as of" date of the inventory. The production department should make an effort to reduce the work-in-process inventory to the lowest point possible. Preferably, during the inventory period, no delivery or receipt of materials from the shop should be permitted, and shipments of goods and transfers of materials should also be discouraged.

Persons taking the inventory should be supplied with the following lists:

1. Materials to be included.
2. Materials not to be included.
3. Materials to be estimated due to physical characteristics.
4. Materials received—no invoices.
5. Materials shipped—no invoices.
6. Materials invoiced to customers—not yet shipped.
7. Materials invoiced by vendors—not yet received.
8. Rejected, salvaged, and scrap material.
9. Supplies and perishable tools.
10. Materials received during inventory.

Forms to be Used.—The principal forms used should be described and their detailed handling and filling in prescribed. The most important are inventory tags and inventory sheets. Their general layout and use are described below.

Inventory Tag.—The tag method is considered most convenient for inventorying materials. The form of Fig. 30 is suitable for all classes of materials. Spaces are provided for name, part number, description, operations performed (if the item is work in process), unit, quantity, location, and counter's initials. The tag is divided into two sections by perforations. The reverse side provides space for recording movement of materials after count is made, which, in the case of slow-moving parts, is frequently done several days before actual date of inventory. All tags should be issued from one place and an accurate record kept of persons

Form Shop 21
INVENTORY 4043
Material Symbol ________
Quantity ________ Unit ________

4043
Material Symbol ________
Description ________
Operations Performed ________
Quantity ________ Unit ________
Location ________
Counted By ________
Remarks ________

Date	Received After Count	Issued After Count

FIG. 30. Inventory Tag

receiving them, together with the location covered by each block of numbers, to localize search for any missing tags at completion of the inventory.

Those taking the inventory should work in teams of two or more, one person to write tags and place them upon the materials, and the other to identify and to count or measure. When a team has completed its work, each departmental supervisor should check every kind or lot of material in his department or storeroom to see that it is covered by an inventory tag completely filled out, before any tags are pulled.

In the case of precious metals, and when incomplete stores records are maintained, a tag is sometimes used containing three sections, and a double count is made of all items. The two lower sections of the tags

are filled in by separate sets of counters and reconciled before the departments are permitted to resume production. Where perpetual inventory records are maintained, such a method is a duplication of effort and is not recommended.

After these checks, which should be made as simultaneously as practicable and near the end of inventory period, these lower sections of the tags are torn off and returned to the person responsible for their issuance. The top sections of the tags remain with the materials to facilitate check for lost tags, and to enable recounts to be made, when necessary. Spoiled tags should be returned marked "Void." All unused tags should also be returned. The issuing authority makes a numerical check and all tags must be accounted for before a department is authorized to resume production.

After this numerical check, the tags are sorted by the material symbol or number and checked against the stores records. Where discrepancies exist, recounts are taken.

The Inventory Sheet.—As the physical inventory and book record quantities are reconciled or adjusted, the quantities are listed on the inventory sheet. These sheets should be compiled according to the class of materials so that a group of sheets will correspond with the items included in one control account. When the stores records have been adjusted, the sheets are sent to the accounting department for adjusting the materials controlling accounts. Work-in-process tags are reconciled to work-in-process accounts and records.

SECTION 6

STORESKEEPING

CONTENTS

SECTION 6

STORESKEEPING

THE STORESKEEPING FUNCTION.—Storeskeeping is a service to manufacturing. Its duties include:

1. Receiving, for safekeeping and protection, all materials and supplies —raw materials, partially worked materials, purchased parts and supplies for manufacturing and plant maintenance, and office supplies.
2. Furnishing materials and supplies, under authorized requisitions, to manufacturing and other departments.
3. Maintaining the necessary storeroom records.
4. Controlling materials manufactured for stores to be used in further production.
5. Holding until needed large stores of raw materials bought at a favorable price for future consumption.
6. Having charge of materials in process, or raw materials, stored for the purpose of aging or seasoning them for use (green lumber, castings, etc.).
7. Keeping the storeroom orderly and clean, having a place for everything, and keeping everything in its place.

Storeroom operation has a direct bearing upon stores record-keeping and the work of the cost department in accounting for materials. If the storeroom fails to do its job efficiently and to adapt its methods to the needs of these other departments, their work may be hampered and made more complicated and costly and less effective.

It is the purpose of this section to deal with storeskeeping only from the standpoint of efficiency in the receiving, storage, and issue of materials and supplies. It will cover, therefore, topics concerning the establishing or reorganizing, equipping, operating, and checking on the work of the storeroom.

The normal place of the storeskeeper in the plant organization and his relationship to the individuals or departments of the factory which he serves or has contact with are indicated in Fig. 1. While such a plan of organization is typical and represents the best practice for perhaps most companies, it is not universal and the storeskeeper sometimes reports to the manufacturing superintendent, the purchasing agent, or even the controller. In certain cases, the storeskeeper of finished stocks or products will report to the sales manager or a merchandise manager, as for example, in the manufacture and distribution of household electrical appliances.

SUPERVISION OF STORESKEEPING.—The organization of the storeskeeping department depends largely upon the plan of company organization, the degree of centralization adopted, the operation of any

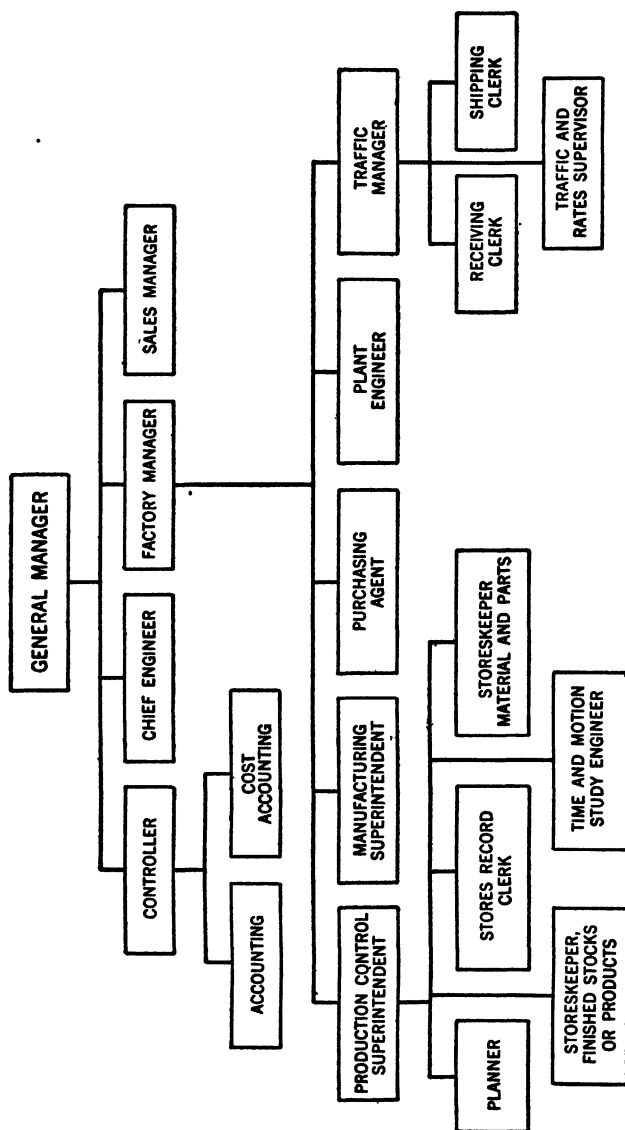



Fig. 1. Place of Storeskeeping in Plant Organization

branch storerooms, the extent to which temporary storerooms are established in production departments, and the relationship of the storeroom to the planning, manufacturing, and accounting departments.

Storeroom personnel consists of a chief storeskeeper, assistant storeskeepers, sometimes a stores clerk or clerks if stores records are kept in the storeroom, and a transportation crew if the storeroom operates its own delivery system to manufacturing departments and moves incoming materials from the receiving department to the storeroom. Often the stores records are kept by a clerk in the materials control section of the production control department, and the storeroom goes no further than entering receipts, issues, and balances on bin tags. Transportation, likewise, frequently is handled by a shop express system under a dispatcher or materials handling manager, or by the truckers in individual manufacturing departments who call at the storeroom for materials.

MANAGEMENT COST IMPLICATIONS.—Storeskeeping in an industrial plant has a direct relationship with certain problems of management which bear directly upon profit-making and which, therefore, need careful attention.

Economy in Cost of Materials and Supplies.—Materials and supplies cost not only what is paid to get them to the factory, but also the expenses incurred in caring for them until they are used, i.e., protecting, handling, and accounting for them. In addition, the carrying charges on excess stocks of finished goods increase the cost of manufacturing. Costs of storage are the overhead expenses (heat, light, taxes, insurance, etc.) for the areas assigned to storage, the wages of storeroom personnel, cost of storeroom and materials handling equipment, interest costs on the value of materials and supplies held in storage, and losses through deterioration or obsolescence.

Maximum Efficiency in the Use of Storage Areas.—Wrong location of storerooms and wasteful use of storage space may interfere with good factory layout, cut down manufacturing efficiency, and tie up floor area needed for increased production. Not only must storage area be laid out effectively in the beginning, but also it must be utilized to the best advantage in actual operation. The accumulation of excessive quantities of materials, or of infrequently used items takes up floor area which should be available for manufacturing.

Maximum Productivity from Capital Investment.—Good storeroom management, coordinated with a well-organized stores record system, prevents the accumulation of excessive quantities of any materials and supplies that are readily obtainable on short notice. Capital unnecessarily tied up in ordinary inventories cannot be used productively elsewhere. Moreover, capital invested in perishable or easily damaged materials and parts may be completely lost when materials are not properly protected.

Coordination of Storeskeeping and Production

ESTABLISHING AUTHORITY AND PROCEDURES.—Three factors of primary importance in shaping storeskeeping procedure are: (1) proper assignment of authority and responsibility for plant opera-

tions, with particular reference to storeskeeping, (2) development of a definite materials terminology and symbolization for use throughout all the departments of the company, and (3) a plan for materials standardization.

Duties of the Stores Department.—It is necessary first to establish simple and definite routines and definitely to fix responsibility for the following work:

1. Receipt of materials into storage.
2. Arrangements for storage of all materials.
3. Custody of, and record-keeping for, materials in storage.
4. Checking physical inventory to assure agreement with records.
5. Prevention of waste through spoilage and deterioration due to poor storeskeeping, lack of protection, etc.

Centralization of Storing and Control of Procedures.—Maximum efficiency in storeskeeping cannot be achieved in those organizations where separate departments are allowed to develop individual routines regarding materials. Centralization of authority is essential to establish proper controls, standard practices, and uniform nomenclature, which aid the work of the engineering department, production control department, and manufacturing department as well as the work of the storeskeeper.

CLASSIFICATION AND NOMENCLATURE.—Following the establishment of management routines for materials, covering all manufacturing departments as well as the receiving and stores departments, and allocating responsibility, attention should be given to the development of a classification of materials and a nomenclature which will be used throughout the plant whenever reference is made to materials.

Classification.—The classification of materials into main groupings is a prerequisite of developing a nomenclature system. In many plants the main groupings of materials will follow the order of accounts shown in the general ledger, thus tying storeskeeping in with the accounting system. The classification developed should be one suitable for use by the engineering department, manufacturing department, and cost accounting department, because all are dealing with the same materials used in production. The major ledger groupings of inventories are:

1. Raw materials
2. Work in process
3. Manufactured parts
4. Parts purchases—finished
5. Finished products
6. Supplies

Nomenclature and Symbols.—Nomenclature designations for materials replace lengthy word descriptions with coded shorthand. They are justified whenever many items differ only in minor details and when these items must be listed frequently on forms and records. While the English language may be universally understood throughout the manufacturing plant, abbreviations, nicknames, and initials will always be used whenever a long name is frequently mentioned. The particular form of abbreviation or symbol is unimportant, but it is essential that such designations meet these requirements:

1. Fit the classification of materials.
2. Be definite and clear.
3. Be simple and brief.
4. Be understood and accepted throughout the plant.
5. Be free from duplication.

Moreover, they must be as foolproof as it is possible to make them; i.e., it should be easy to avoid mistakes in recording and interpreting them. Thus, if numbers and letters are used together, certain letters must be omitted because of their similarity to numbers or other letters. These are I, O, Q, and Z, which resemble 1, 0, and 2.

Many plants and management consulting firms have developed their own systems of nomenclature and symbols. When classified by characteristics, these fall into two main groupings, as described below.

Arbitrary Systems.—A different number or letter symbol is assigned to each item as it comes up for designation. There is no attempt to give adjacent numbers to similar items. Thus, number 5,196 may refer to a heavy casting, and number 5,197 may refer to a cotterpin. Low numbers usually indicate that an item has survived a number of years without a change, and items of recent adoption and frequent use are labeled with numbers running up into the thousands or even millions under some systems.

The size of these numbers may be reduced by introducing letter prefixes and starting from zero again, proceeding until the number once more becomes unwieldy, and then changing the prefix. Thus, designations may run from 1 to 10,000, then from A1 to A10,000, and so on up through the alphabet.

A parts catalog, with items classified according to description and function, and cross-referenced with the arbitrary systems of nomenclature and symbols, should be kept up to date for the use of designers and clerks.

The simplicity and flexibility of the arbitrary system are very much in its favor, and many logical but complicated systems begun on a different basis eventually become nothing more than arbitrary systems.

Classified Symbol Systems.—Classified systems fall into two subdivisions, generally known as decimal and mnemonic systems. The **decimal system** uses a separate number to indicate the specific form of each general characteristic. Ordinarily this system is too minute and cumbersome. It is applied to advantage in libraries where a detailed classification is required for use by a few cataloging experts. The Dewey decimal classification is commonly used for this purpose.

The **mnemonic** system attempts to base nomenclature on letters suggested by the abbreviation or the initials of an item. In any but the smaller shops, brief designations are soon duplicated for many different items, so that it is necessary to describe several additional characteristics. A screw thus might bear the symbol SFSMR.375x1.15N (stored item, fastening class, screw, machine type, round head, .375 in. in diameter and 1.15 in. in length, with a nickel finish). As a result, the symbol may become almost as burdensome as the word description it replaces.

Combined Systems.—The best features of each of the foregoing systems can be conveniently combined to meet the need of individual plants. First, it is necessary to divide all items to be identified into major classifications. The basis of this division will vary according to the customs and individualities of each plant. In some cases all items performing the same function will comprise one class. This method is generally the most desirable. Thus, screws, nails, cotterpins, washers, etc., may all be classified as fastenings. The items in a machine shop

might all fit under the following classifications: (B) bearings, (C) cams, (Cl) clutches, (F) fastenings, (G) gears, (J) jigs, (P) pipe, etc. If functions are carefully selected, any new item will fall into one of the classifications.

Second arbitrary designations may then be given to the items within the major groups. Sometimes, before resorting to arbitrary designations, it may be desirable to include a second or third mnemonic or decimal classification, or to reserve a certain range of numbers for a definite group, in the same way that rooms on the second floor of a building are 200, 201, etc., and on the third floor, 300, 301, etc. However, it is difficult to foresee the number of new items which will be added to each classification.

Planning for Storage

BASIS OF PLANNING.—The principles developed in this Section apply not only to the planning of storerooms, but to the layout of storage areas in manufacturing departments and the layout of storage yards. Planning for stores cannot be done by any one formula. The requirements of manufacturing, accounting, etc., must be carefully considered and combined to give the solution which is most desirable for the whole plant. To accomplish this end, it is first necessary to (1) examine all the factors which may influence the final plan, (2) consider each requirement and its limitations, and (3) determine the combination which will provide maximum service balanced with minimum expense.

Information to be Compiled.—Information on the following topics should be compiled and studied before making definite plans:

1. Items to be stored—complete data.
2. Available space.
3. Facilities for intraplant transportation.
4. Storage procedure with particular reference to stores control.
5. Storeroom equipment.

Items to be Stored.—All items to be stored should be listed in detail as to:

1. Size and weight of the unit in which the items will be handled. The unit may be a containerful rather than a single article.
2. Quantity usually requisitioned and the frequency of requisitions.
3. Place where the material is received and the points at which it is to be delivered.
4. Maximum number of units which will be stored at one time. This amount is determined by the quantity in each new lot, and the quantity of the old lot on hand when the new lot arrives.
5. Minimum quantities to be stored.
6. Space or special care required in handling and transporting.
7. Special requirements of light, heat, temperature, humidity, ventilation, protection, etc.

Available Space.—There are many specific factors which must be investigated in regard to the nature of the space available for storage.

1. Areas, and their adequacy, available for storing and floors on which located.
2. Shape and dimensions of areas as related to sizes of items to be stored.

3. Position of the areas with reference to the manufacturing departments which they will serve.
4. Location with reference to elevators.
5. Permissible floor loads.
6. Ceiling heights.
7. Building laws, fire laws, building, elevators, sprinkler, safety, and special materials codes governing the construction, alteration, and operation of plant and facilities.

Facilities for Intraplant Transportation.—The handling of materials and parts stored offers many problems which affect the efficiency and economy of storeroom operation and the service given by the storeroom to the manufacturing departments.

1. Kinds of materials handling equipment suitable in moving and storing the respective materials.
2. Extent of elevator service needed.
3. Degree to which fork or lift trucks and pallets or skids can be utilized in moving materials into and from stores.
4. Applicability of conveyor systems.
5. Capacities of the handling equipment—units per hour of the various kinds that can be moved over the proposed routes and distances.
6. Facilities for loading and unloading. Traffic problems in regard to industrial trucks and motor trucks.

Storage Procedures and Storeroom Equipment.—The factors of storage procedures and storeroom equipment are so important as to require extensive detailed treatment under those two individual headings, as developed in the subsequent pages.

Methods of Storing

STACKING, PILING, OR ARRANGING STORES.—Before proceeding to the actual layout of a stores area, it is necessary to give attention to the methods of piling that will be used in actual storeroom operation. Good storing procedures will bring about the following beneficial results:

1. Efficient utilization of space (concentration).
2. Accessibility of materials.
3. Flexibility of arrangement.
4. Actual physical turnover of materials.
5. Ease of physical counting.
6. Reduced need for handling equipment.
7. Ready inspection of materials in storage to keep inventory up to date and detect any pilfering.

DEFINITIONS.—Preliminary to any consideration of methods of piling, it is necessary to establish the following definitions:

Item: Any one kind of stores; for example, 2-in. round-head wood screws. If a change is made in any one of the above characteristics, a new item is created, as for instance, when a nickel finish is added to the original screw.

Article: Any single piece, as one 2-in. round-head wood screw.

Pile: A group of units. When the piling is not done systematically, an irregular heap results. Systematic piling may be done in one or more of the forms defined below.

Column: A vertical, regular pile; one unit wide, one deep, and two or more high.
Stack: A regular pile, two or more units wide, one deep, and two or more high. A cubical stack consists of two or more adjacent columns piled along a straight line. Stacks may be also pyramidal in form.
Tier: A separate unit of a column, or horizontal row (layer) of a stack. Tiers are numbered in the order of piling, from the bottom up.
Block: A regular pile, two or more units high, wide, and deep. Two or more adjacent stacks.
Course: The horizontal layer of a block. Two or more adjacent tiers.
Section: The vertical layer of a block.
Lot: The quantity of units usually ordered at one time and received in one shipment.

SELECTION OF PROPER UNIT SIZES.—It is highly economical to have materials pass from the receiving room to point of utilization with as little handling as possible. Under an ideal arrangement, goods would arrive at the plant in containers to be stored, issued, and transported to manufacturing department without unpacking and packaging. This standard size container, rather than the small, individual article, becomes the unit in which the item is handled. When items are large, such as bags of cement or castings, the unit, of course, is also the article itself. Units containing a multiple of small items, small parts, fastenings, and other articles save labor for the procurement, stores, and accounting departments.

METHODS OF PILING.—In **cubical piling,** packages or bags are piled directly on top of one another to form columns and then rectangular blocks. Cubical piling is economical in the use of space and easier to inspect, it is easy to keep the piles regular and uniform, the units are easier to count, and there is a minimum of exposure to the weather. Cubical piles should not be permitted to reach a height that will prevent the effective operation of the sprinkler system, and with some types of material there is danger that too high stacking of the material will crush the lower units. While the height of cubical piles is often limited by their stability, walls, partitions, and bins may be used in many cases to provide the necessary support. In some cases **mezzanine floors** will greatly increase the capacity of a storage area.

Uniform, cubical piling is much easier to count than irregular, circular, or pyramidal piling. Definite dividing spaces between items, and units placed so that labels are visible will simplify the taking of the physical inventory and prevent reordering in the belief that there is too little on hand. Whenever possible, goods should be piled so that they practically make their own count. This result, in the case of goods piled on the floor in a standard place, may be accomplished by a number scale painted along the floor or wall, reading in the number of units from the starting point to the edge of the pile. When a moving-division system is used, the total inventory is the difference between the readings at the two ends of the moving division, or gap, subtracted from the total. (See Fig. 2.)

Order of piling and removing must be uniform if stowage systems are to operate smoothly and neatly. Here again, there is no one best system, but a good one should be adopted and followed. One standard procedure is to begin a column in the back, left-hand corner of an area

and come forward with adjacent columns until the predetermined depth of the block has been reached. The next column is then started in the back, to the right of the rear column and the section just completed. If the first-in items are to be the first out, which is desirable in the case of goods which deteriorate, the procedure is almost exactly repeated. The extreme left front column is first removed (the rear column, which

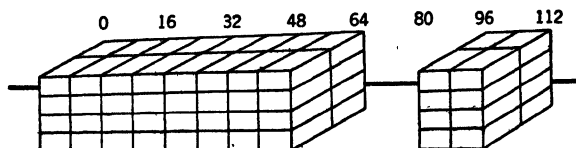



FIG. 2. Wall Scale to Facilitate Counting of Stored Items.

is actually the first in, is not directly accessible), then the rest of that section, one column at a time, and next the adjoining section are removed in the same way. Of course, this procedure must be modified when individual columns are not stable.

"Pyramidal" piling has the advantage that it enables round or spherical objects to be placed in a pile which is self-supporting after the bottom layer has been braced. The peaked shape of the pile renders it easy to protect from the weather by tarpaulins. The following formulas give the number of units in pyramidal piles.

For a pyramidal stack: Number of units =

$$\frac{\text{Number on bottom tier (Number of tiers} + 1)}{2}$$

For a full pyramid in both directions: Number of units =

$$\frac{\text{No. on bottom course (No. of courses} + 1)\ (2 \times \text{No. of courses} + 1)}{2}$$

METHODS OF ISSUING: FIRST-IN FIRST-OUT SYSTEMS.—When a new lot of material arrives, it is often piled in front of the old stock, so that the new units are used first. As a result, packages in the bottom of the stockpile are not removed unless the inventory becomes dangerously low, and then they may be found to be deteriorated or out of date. One solution is to remove all the old stock from the storage area, pile the new stock in the back, then put the old stock back in the front. This method requires tedious extra handling and adds nothing to value of the material. Several other more practical suggestions are listed below.

Coupon Systems.—Two coupons are made out for each container. One is attached to it; the storeroom address of the container is noted on the other coupon, and it is placed in the coupon file. When material is requisitioned, the oldest coupon is taken from the file, and its corresponding container is located according to the address on the coupon.

This system is not convenient when containers must be piled in large blocks and all containers are not readily visible or accessible without removing the more recent lots which may have been piled in front.

Double-Area System.—While the double-area system is often referred to as the "double-bin" system, the latter connotation tends to limit the application of the principle to bins only, whereas the plan applies also to any area or equipment used for storage.

The area allocated to an item is twice that required for one lot. As each new lot is received, it is stored in the empty area, but not used until the old lot in the other area has been depleted. But often the additional area or storage equipment required for this system will not be available.

Moving-Division System.—The moving-division system may be used with goods stored in cubical piles in an oblong area, as has been shown

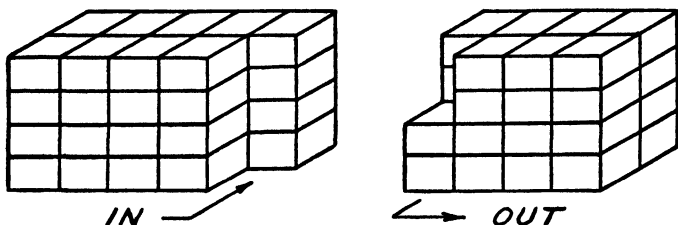



FIG. 3. Method of Storing and Issuing Items Under First-In First-Out Plan

in Fig. 2. Goods are removed from one end of the pile, let us say the left, so that as the pile is depleted, the point of removal moves to the right. When a new lot arrives, the pile is started at the extreme left of the area and extends as far to the right as necessary (see Fig. 3). Sufficient area is allotted to the item so that there is always a dividing space between the piles. Goods are removed from the right of this moving division and added at the left, so that it repeatedly moves across the area from left to right.

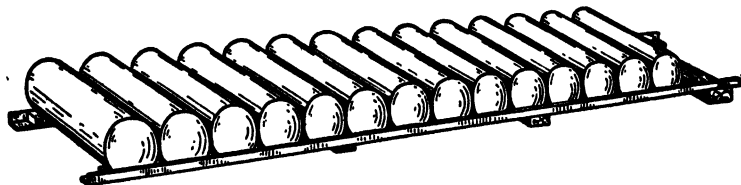



FIG. 4. Gravity-Feed Rack for Storing Drums, Kegs, or Barrels

Gravity-Feed Systems.—Certain types of materials dispensed in bulk may be stored in gravity-feed storage bins; common examples are grain and coal dispensers. This principle may be applied also to circular package goods by constructing a sloping rack the pitch of which must be determined by the nature of the units to be stored (see Fig. 4). Additions are made at the upper end of the rack and removals from the lower end. If desired, a counter may be attached to the rack.

Storeroom Equipment

SHELVING AND BINS.—Over-all efficiency and flexibility of the storeskeeping process can be greatly increased by use of the proper storeroom equipment. In some companies the maintenance department constructs most of the shelving, bins, etc., which are made from lumber and plywood, designing the installation to fit the particular requirements. Standard steel equipment, however, has come into wider use than wood shelving and may be purchased in a variety of forms and sizes from manufacturers specializing in the field.

ADVANTAGES OF STEEL SHELVING.—Manufactured sheet-metal equipment has the following advantages:

1. Standardization. Standard units can be obtained from manufacturer's stocks at low cost because of mass production.
2. Compactness for shipping and handling. Units are shipped knocked down for ease in handling.
3. Easy assembly. Units are readily erected at point of installation by bolting the parts together; also can be easily taken apart when changes are necessary.
4. Flexibility:
   a. Interchangeability. Standardization permits units or rows to be moved and rearranged whenever desirable without changing the general layout.
   b. Adaptability. To adapt them to a variety of uses, units are designed and drilled so that they can be assembled or reassembled as open shelving, closed shelving, bins, partitioned bins or shelving, subdivided tiers, etc.
   c. Auxiliary units. Besides shelving and bins, other equipment can be installed, such as cabinet sections, cabinet bases with shelving above, deep cabinet bases with shallower cabinets or shelving above, drawer units, sloping or other special bin units, etc.
5. Expansibility. Standardization permits the purchase and addition of like or similar units when more storage facilities are needed.
6. Strength. Volume for volume, steel equipment is far stronger and more rigid than wood.
7. Durability. Steel equipment is not easily damaged, does not wear or break, retains its enamel coating, and has unlimited life if properly maintained. Wood shelving deteriorates by warping, sagging, cracking, breaking, wearing, and splintering.
8. High salvage value. Equipment can be taken down and reused for other purposes, or stored until needed, or sold to dealers at a good price if a new kind is to be installed. Wood shelving is practically destroyed when taken down.
9. Maximum storage capacity. All parts are thin and occupy little space; no heavy uprights and shelves are used as in wood shelving. Subdividing wood shelving cuts down storage space, especially if flexibility is retained by using removable subdividers which are usually small open-end boxes.
10. Safety. No injuries result from the steel equipment, whereas damaged wood shelving is a frequent cause of splinters in hands and arms of stores clerks.
11. Absence of fire hazard. Steel equipment is fire resistant. It will not burn nor readily buckle. Contents may burn without seriously

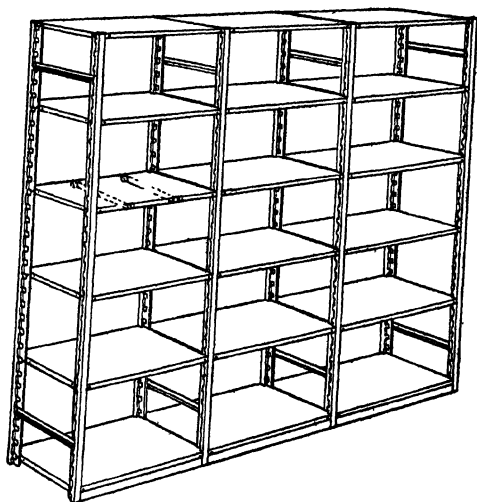



Fig. 5. Open-Type Shelving

Fig. 6. Closed-Type Shelving in Double-Faced Assemblies

injuring anything but the enamel, whereas wood shelving itself may catch fire and increase the fire damage.

12. Protection against vermin. Steel shelving is immune from damage by rats, mice, and boring insects, and does not harbor such vermin or bugs.
13. Cleanliness. Because of its smooth, hard surface, thin sections and smallness of cracks at joints, steel shelving can be readily kept clean by brush or cloth.

ADVANTAGES OF WOOD SHELVING.—Wood shelving has a few advantages:

1. Cheapness and quickness of installation. It can be made from cheap ordinary lumber obtainable locally, and without much waste if bought in proper lengths. It should be erected by a carpenter, however, for a good job.
2. Adaptability to local conditions. While special steel equipment could be obtained for special conditions, such as peculiar shape of storage spaces, wood shelving can be designed and built on the job to fit into unusual layouts.
3. Protection for delicate equipment. Wood is soft relative to steel and more resilient. Fine tools and delicate instruments which might be damaged if dropped or moved around on steel shelving, are more safely stored on wood. There is no reason, however, why wood surfaces, racks, or trays might not be built on steel shelving to provide the softer surfaces, unless the extent of such an installation is such as to make wood shelving much cheaper.

TYPES OF EQUIPMENT.—The principal types of equipment are listed below. All of these varieties may be purchased from manufacturers of steel shelving or may be constructed by maintenance departments in case wood shelving is desirable or necessary for any reason.

When there is an early limit to the height to which units may be piled, or when there is a great variety of items, **open-type shelving** will greatly increase the capacity of the floor area (see Fig. 5). **Sway braces** may be added if the loading is heavy. (Storage shelving and rack illustrations from Berger Mfg. Div. of Republic Steel Corp.)

Closed ends and backs added to open shelves give greater stability to piles and may also serve to separate items (see Fig. 6).

When **bin fronts** are added to above equipment, small, irregular objects, fastenings, etc., may be accommodated. The shelving has now become a series of storage boxes (see Fig. 7).

When a small number of many items must be accommodated, **bin dividers** may be inserted to separate the items, as shown in Fig. 7. These do not give any structural support to the whole assembly.

Combined sloping shelf inserts and **shelf subdividers** are often convenient when each article is different and must be readily visible to facilitate quick selection (see Fig. 8).

Counter-height ledges added to any of the above shelving provide convenient temporary storage space when goods are being added, removed, sorted, etc. (see Fig. 9). These sections may consist of a variety of combinations, such as all-shelving below and shallower all-shelving above, all cabinets, with either hinged or sliding doors, all-cabinets below and all-shelving or bins above, all-shelving or bins below with all-cabinets above, and in other arrangements.

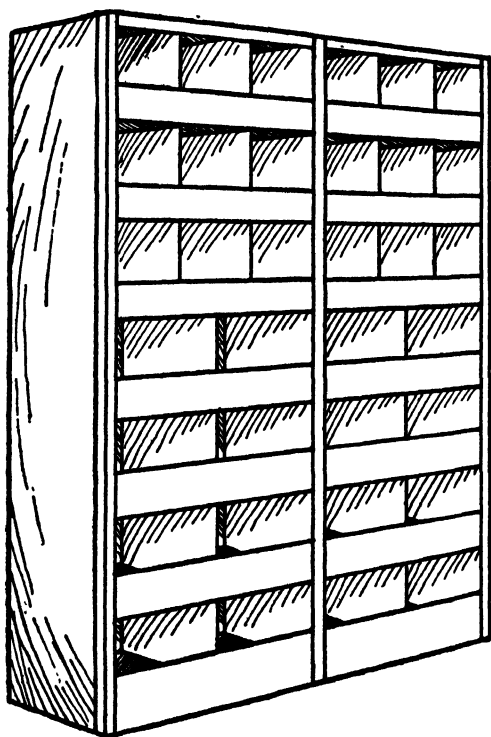



FIG. 7. Use of Bin Fronts and Bin Dividers in Closed-Type Shelving

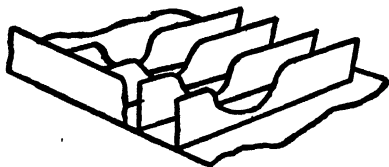



FIG. 8. Combined Sloping Shelf Insert, Shelf Subdividers, and Drawer Insert

Roller shelves are now seldom used, although at one time were in some favor. Their purpose was to enable heavy articles to be piled and removed with less difficulty. They may be used for the storage of heavy tools or dies.

Doors provide protection against theft, dust, etc. In many cases, sliding doors are preferable to doors on hinges. **Drawer inserts,** of which a section is shown in Fig. 8, not only give protection but also provide greater capacity for small articles than does bin type shelving, and the drawers may also be removed to function as tote boxes.

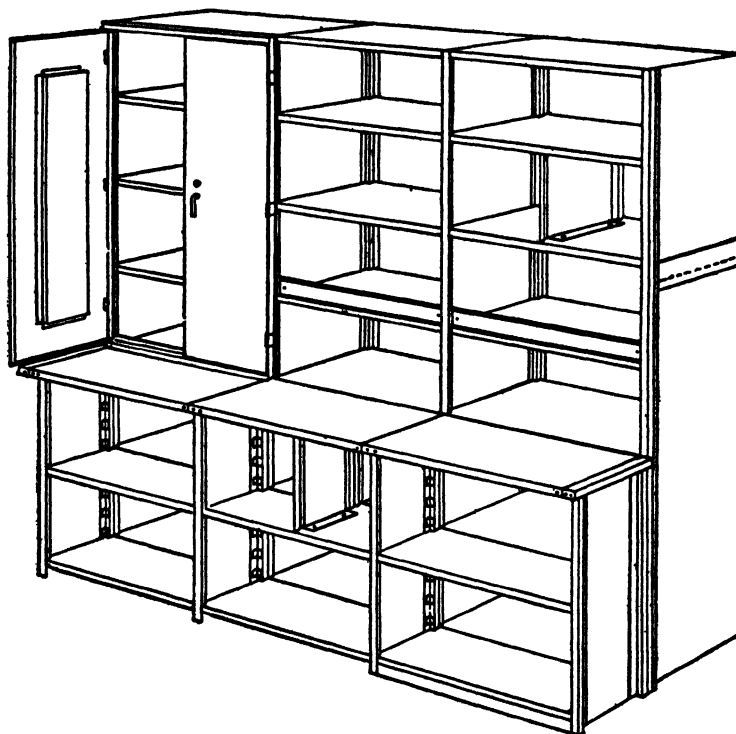



Fig. 9. Cabinets with Counter-Height Ledge and Bin Sections

Open-type removable bins are useful for small items such as nails, bolts, etc. (see Fig. 10). They are often constructed of a size to hold one keg of nails. Accessibility of the bins saves time and trouble in storing and issuing unpackaged items.

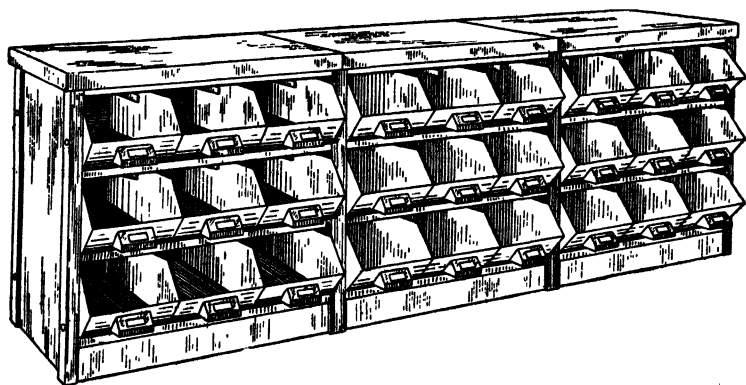



Fig. 10. Open-Type Removable Bins in Counter Unit

Maximum flexibility of storage arrangements is attained with **stack racks** (see Fig. 11a). Individual units are so constructed that they may be locked firmly together without tools, enabling temporary or permanent storage units to be assembled quickly with a minimum of cost.

Stacking boxes are essentially tote boxes with an interlocking feature which enables them to be stacked to form a stable, self-supporting pile (see Fig. 11b). They are particularly useful in storing and transporting small articles and fastenings because they may be easily carried and quickly placed in a self-supporting pile for temporary storage, or, when

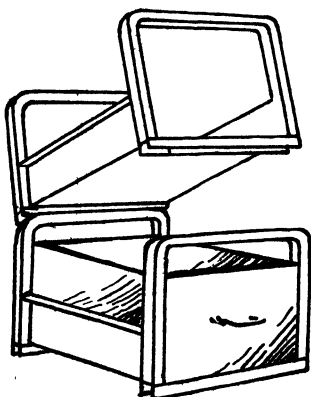



Fig. 11a. Stack Racks with Drawer Inserts

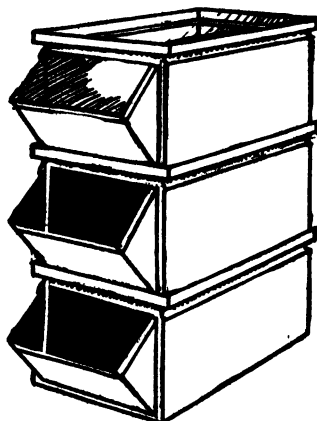



Fig. 11b. Stacking Boxes

they contain several different articles they may be piled on an assembly bench within convenient reach of the operator. Sloping bin fronts permit ready access to the contents of all boxes in any column without unstacking.

Storage racks for bar stock are made in many varieties. Those for lumber, bar stock, or pipe, etc., often consist of posts with horizontal arms attached (see Fig. 12). Other racks are made of structural shapes and are more solidly built. One such rack weighing 2,064 lb. was built to carry a total load of 250,000 lb.

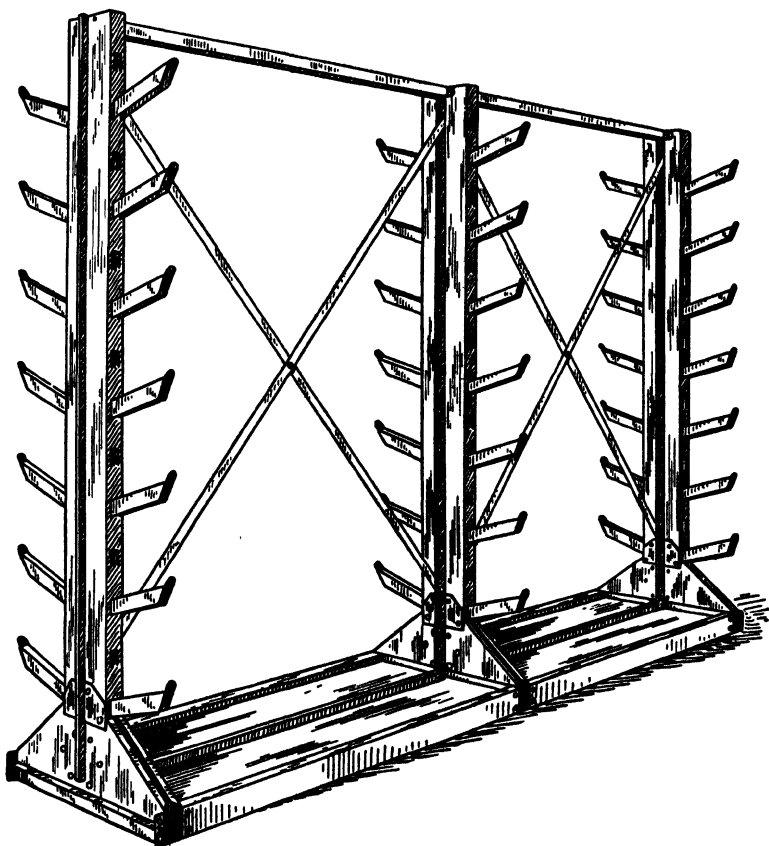



FIG. 12. Rack for Lumber, Bar Stock, or Pipe

Weighing scales are in wide use in storerooms for bulk materials issued by weight, such as powdered compounds, nails, etc. These scales are also employed for measuring quantities of small items like screws, bolts, and other miscellaneous stores which are given out in approximate amounts instead of by actual count. Tables or diagrams may be prepared showing how much, say 100, such items weigh and the approximate quantity needed can then be obtained by weighing. A typical scale for this purpose is shown in Fig. 13.

Movable ladders are required in storerooms to give access to materials where shelving and bins are over 8 ft. high. These ladders may be mounted on platforms equipped with wheels or casters for maximum

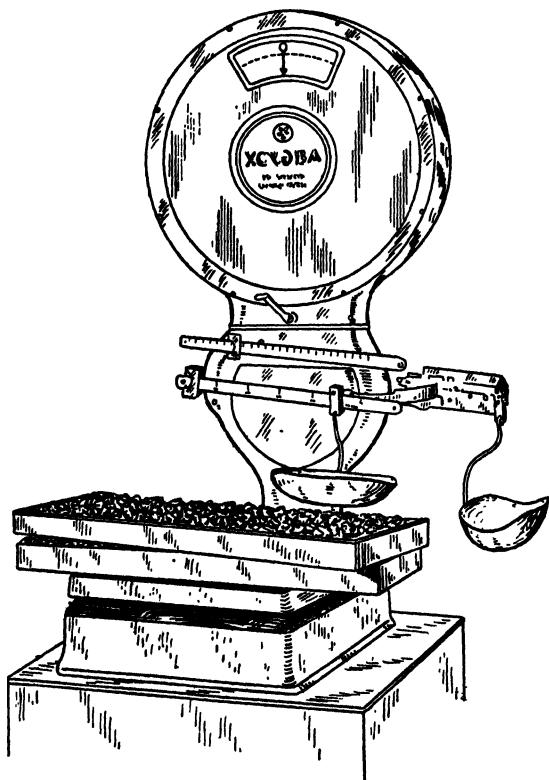



FIG. 13. Weighing Scale for Counting and Issuing Bulk Materials in Storeroom
(Toledo Scale Co.)

mobility (see Fig. 14a), or they may run on overhead tracks or guides at the top and be fitted with wheels at the bottom, for use along fixed rows of shelving (see Fig. 14b).

EQUIPMENT FOR HANDLING MATERIALS.—Materials handling is a proper consideration of storeskeeping in the receiving and storing of materials and their delivery to manufacturing departments. Trucks of many kinds are universally employed for this purpose. They range from the common platform truck or box truck for hand operation to the hand lift truck and the numerous kinds of electric and gasoline trucks, tractors, lift trucks, fork trucks, elevating trucks or portable elevators, and related varieties which are available.

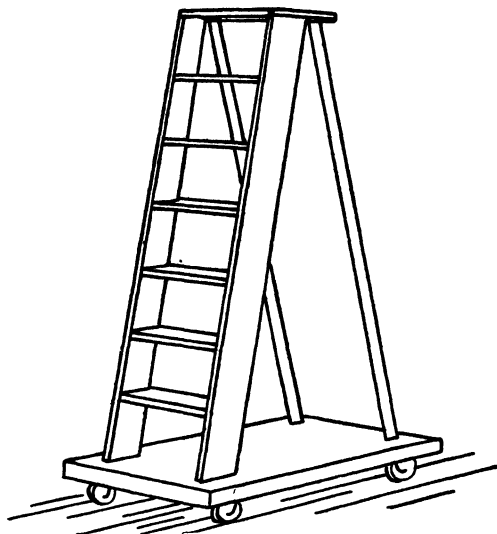



Fig. 14a. Self-Supporting Movable Ladder

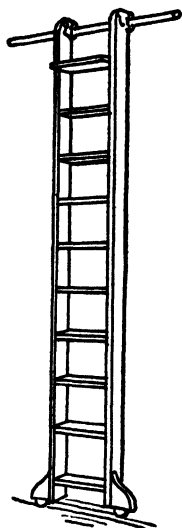



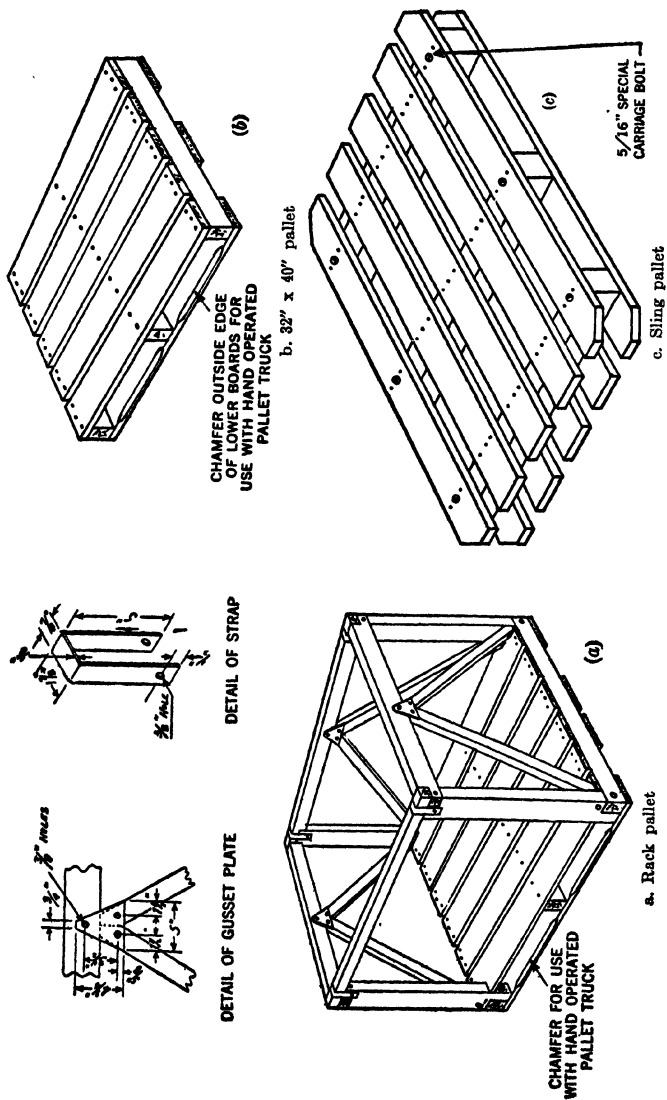
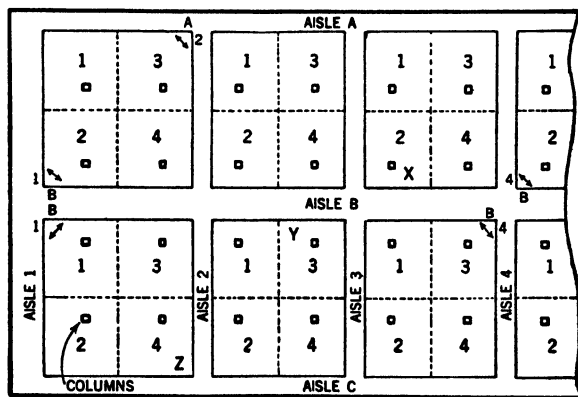
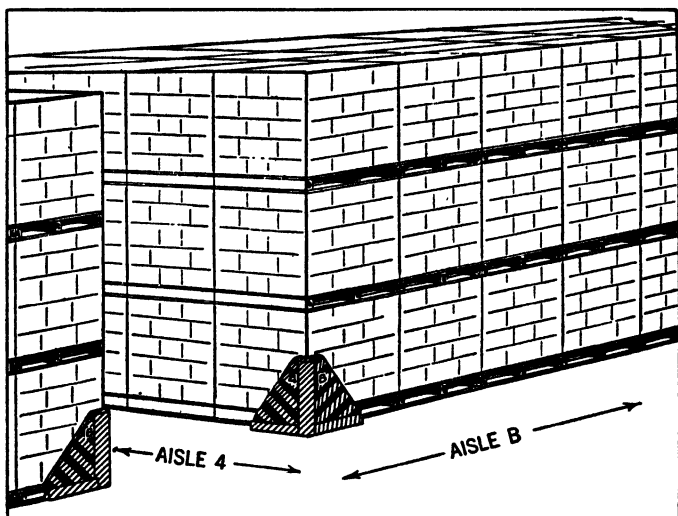
Fig. 14b. Movable Ladder Operating on Overhead Rail Guide

When industrial trucks are used, it is advisable, as far as possible, to store materials on skids or pallets (Fig. 15a to 15e) which are then handled by lift trucks or fork trucks. Materials suitable for such a method of handling, upon their arrival at the plant, should be made up into standard skid or pallet loads. Often the vendor may be asked to package the items in standard quantities of issue. In other cases the items may be put in standard quantities into boxes or containers as the shipment is unpacked, checked, and inspected in the receiving department. The practice is increasing to go even further and to have vendors actually ship the goods on skids or pallets in standard loads or number of pack-

a. Rack pallet

b. 32" x 40" pallet

c. Sling pallet

Fig. 15a-c. Pallets and Pallet Racks
(Pallet Sales Co.)

EXAMPLES OF NOMENCLATURE FOR PALLET LOAD LOCATION

Pallet	Key	Explanation
X	3-2-B	Aisle B-Section 2-Beyond Aisle 3
Y	2-3-B	" B- " 3- " " 2
Z	1-4-C	" C- " 4- " " 1

Top: Vertical stacking of pallets with corner guard protectors, painted yellow and black, serving as aisle markers.
Bottom: Storeroom layout with bay areas divided into quarters or smaller divisions.

FIG. 15d. Storeroom Arrangement for Pallet Loads
(Materials Handling Machinery Co.)

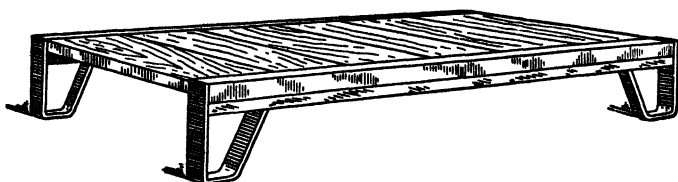



Fig. 15e. Skid

ages, so that unloading of cars, checking shipments through receiving, and placing them in stores are all done with the aid of lift or fork trucks. If the skid or pallet load is itself a standard unit of issue to the manufacturing departments, the items may be delivered on these carriers, thus completely eliminating all manual handling through the storage operations.

Such use of skids and pallets will improve the efficiency of storing many materials. Bagged materials, knocked-down cartons, boxes of parts or supplies, sheet stock, etc., are nowadays usually handled in this manner in well-run plants. Lift trucks or fork trucks will stack or pile the platforms to heights up to 16 or more feet, without manual handling. Pallets give greater piling stability because they are, practically, shallow boxes without sides. The top surface supports the load and the bottom one spreads the pressure over the entire surface of the material beneath.

Special pallets may also be designed to accommodate articles which could not be stacked ordinarily in cubical piles, such as drums, irregular castings, or large pipe stock (see Fig. 16).

Small racks used for the storage and handling of different varieties of cut bar stock are shown in Fig. 17. These racks, designed and constructed by the user, are stacked one on top of another by means of the angle shapes at top and bottom, and are handled by fork or lift trucks for transportation to manufacturing departments.

Certain cylindrical and spherical objects such as coil stock may be supported in racks as shown in Fig. 18. These racks may be designed to permit tiering in a manner similar to that used with stacking racks or boxes.

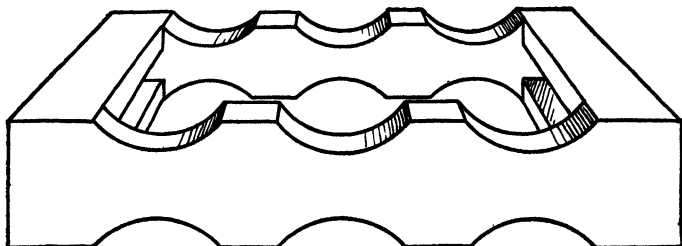



Fig. 16. Special Pallet for Handling and Piling Cylindrical Stock

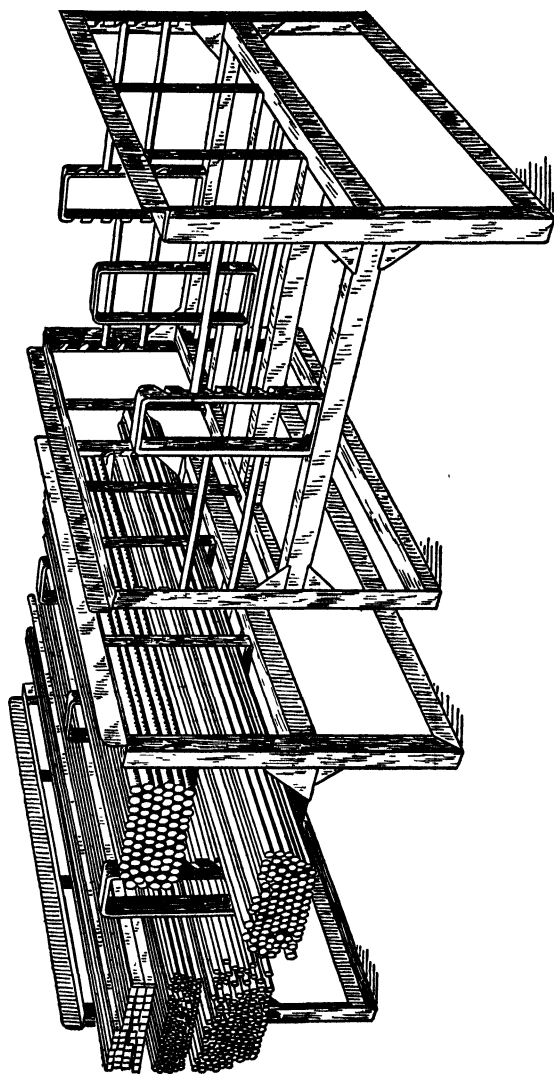



FIG. 17. Racks for Short Bar Stock Designed for Stacking and Handling by Fork or Lift Trucks
(Singer Mfg. Co.)

High lift or elevating trucks, properly called portable elevators, are convenient for storing heavy objects, or large quantities of objects, in high bins or shelves.

Where heavy or unwieldy objects or bulk materials are handled in and out of stores, and also when large amounts of materials are handled regularly over standard routes, the storeroom is often served by conveyors of various kinds. These conveyors sometimes connect the storeroom with a manufacturing department which it supplies with materials on regular schedule. Among such devices are roller conveyors, belt conveyors, slat conveyors, portable conveyors, overhead chain conveyors, tramrails, cranes with buckets or magnets, and numerous other kinds of handling equipment.

In the selection of material handling equipment for the storeroom, it is best to consult material handling engineers and manufacturers of conveyors, industrial trucks, etc., who can recommend both handling equipment and types of storage equipment which are best used in conjunction therewith.

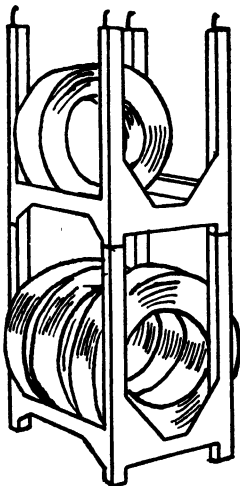



Fig. 18. Stacking Racks for Coil Stock

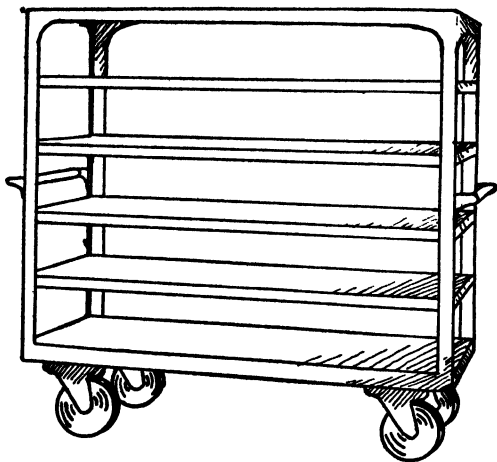



Fig. 19. Shelf Truck for Storing and Handling Material

It is sometimes advisable to combine storing and handling equipment into one in the form of special hand trucks. When a large variety of parts is needed in many temporary locations about an assembly operation, they may be stored on a shelf truck (see Fig. 19) and readily moved to positions convenient for the operator. The added investment in mobile equipment is compensated for by a reduction in the stationary shelving and reduced handling time. Any of the modifications discussed in connection with the permanent shelving, of course, may also be added to the portable arrangements.

Layout of Storage Areas

CALCULATIONS PRELIMINARY TO LAYOUT.—When all the facts and data are assembled in regard to the kinds and quantities of material to be stored, the kind, size, and space requirements of storeroom bins and shelving necessary, and the material handling facilities which must be provided, the layout of storage areas may be planned. From the information collected, the following calculations can be made:

1. **Area needed for each article.** This may be influenced by the following factors:

a. Size of article—length, width, height.
b. Weight of article.
c. Number of units which might be cared for at one time.
d. Container, if any, in which article is kept.
e. Kind of shelving, bins, or racks required.
f. Methods of storing or piling.
g. Methods of handling the material in and out of storage.
h. Special accident, fire, or explosion hazard or other characteristic of material storage.
i. Frequency of demand for article.
j. System used for control of quantity.

2. **Size of aisles in storage areas.** Aisles in the storeroom must be sufficiently wide to accommodate handling of materials, not only in straight-line travel, but also around corners, and when loading and unloading.

LOCATION OF STORAGE AREAS.—Organization and location of storage areas must depend upon the individual needs of each plant. Even among manufacturers engaged in the same industry, the locations of stores areas vary greatly. The variations result from differences in plant size, building facilities (one- and two-story buildings, scattered plants, etc.), production requirements, process arrangements, special department needs, and other factors. Types, quantities, size, and nature of the materials to be stored, also create special problems of storeskeeping organization. Despite these limitations, these basic principles are important:

1. Storeroom areas and arrangements should be developed to provide maximum storeskeeping service at a minimum cost; i.e., storeroom placement must serve the convenience of manufacturing processes in keeping with both space limitations and holding down clerical costs.

2. Every storeskeeping plan should provide for a maximum of flexibility to meet changing conditions. Plant rearrangements or changes in manufacturing procedures may alter storeskeeping service demands.

When incoming materials are bulky or require special handling equipment, it is often desirable to store them near the receiving department or to move them directly from receiving platform to the production center where they are to be used. In some instances bulkiness or weight of materials may require that manufacturing departments be located near the receiving department. Items manufactured in the plant to order, which ordinarily might be stored for a time, likewise often should go directly from the producing departments to the production floor,

where they are to be further processed or assembled. All such items, however, whether purchased or produced, should be recorded, and care must be taken to provide adequate protection against any possible loss or damage.

CENTRALIZED AND DECENTRALIZED STOREROOMS.—There is some advantage in having decentralized storage or departmental storerooms for items used only by single departments, thereby avoiding unnecessary handling, record-keeping, and delays in delivery to production areas. The centralized storeroom has certain advantages but also some disadvantages.

Advantages of Centralized Storing.—The advantages of centralized storing arise to a considerable extent from better control. They are:

1. Better supervision to obtain most efficient operation.
2. Fewer persons required in storeroom.
3. Entire store personnel becomes familiar with all materials stored. Less trouble if someone is absent or quits.
4. Usually better service from storeroom. More leveling off of load on personnel and less delays in deliveries to departments.
5. Personnel can be kept busy checking physical inventory, making up orders in advance of delivery time, straightening up material on shelving, putting materials away, etc.
6. Better layout of storage areas, and more efficient use of bins and shelving.
7. Less total space occupied. No duplicate areas, such as for desks and make-up of orders, and less spare bins than if stores are decentralized.
8. Better control over inventories and less total inventory carried.
9. Less total space occupied for storage.
10. Less obsolete stores carried and quicker discovery of practically duplicate items and of items declining in use, so that these can be studied and perhaps dropped.
11. Easier to take periodic physical inventory checks against balance-of-stores records.
12. Storeroom records all in one place and system of operation under direct control of chief storeskeeper.
13. Clerical costs are lessened.

Disadvantages of Centralized Storing.—The disadvantages come largely from the danger of poorer service to production departments. They are:

1. Storeroom may be too far away from some departments, so that longer trucking distances are involved.
2. Considerably more trucking often is necessary.
3. Rush needs are less quickly filled.
4. Departments may sometimes have to wait for materials if storeroom work piles up, or breakdowns of elevators or trucks occur.
5. Departments must anticipate their needs a little earlier. Under good production control, however, this earlier action would be provided for.

Temporary Decentralization.—It is not always necessary to build storage areas to achieve decentralization. To an increasing extent, portable and special equipment for the purpose of readily moving stored items into manufacturing areas is coming into use. Movable equipment is now available, with drawers, shelves, racks, etc., which can be locked to pre-

vent the removal of the material during nonworking hours. The shelf truck is an example (Fig. 19). A number of companies have provided temporary storage areas by using stacking boxes or bins which can be transported and arranged for special purposes at any point along the production line.

FACTORS AFFECTING LOCATION OF STORES.—From the standpoint of materials handling, it is desirable that the flow of materials from raw materials receiving platform to finished goods shipping platform be as near a straight-line flow as possible. This purpose can be accomplished only by considering layout of the plant as a whole and placing the storage areas in a direct line between successive processes. In practice there are many requirements and limitations that will necessitate a modification of straight-line flow. The extent of these modifications and also the areas allocated to individual articles within a storeroom will be governed by the following factors:

1. **Difficulty in transportation.** Articles which require special equipment, labor, or care in transportation should be transported as little as possible.
2. **Special dispensing equipment required.** Liquids that must be specially measured and articles that must be weighed, etc., have first claim on stores area adjacent to the measuring equipment.
3. **Frequency of requisitions.** For items requisitioned frequently and in small quantities, the distance from the issuing window to the shelf location should be shorter than for articles withdrawn less often and in large quantities. This principle also applies to the height at which items are stored, and to their location in open-floor storage. The storeroom attendant should be able to obtain frequently requisitioned articles with a minimum of effort.
4. **Convenience in storing and handling.** It is customary to store together all articles of similar size or shape even though they may be required by different production departments. Thus, all small parts and fastenings should be kept in one section, bar and pipe stock in another, and so on for all classes of items stored. This arrangement permits specialization of the storeroom and avoids duplicate inventories in different parts of the plant. Heavy or bulky items, of course, should be kept on lower shelves, or stored on the floor.
5. **Advantages of storage areas adjacent to production departments.** In direct opposition to the consideration discussed above is the desirability sometimes of decentralizing the stores areas so that all supplies for each production area are located next to this area. Such an arrangement eliminates production delays caused by lack of materials, because the stockpiles come under observation of the dispatcher or foreman, who can make sure that materials are always at hand when needed.

PLANNING THE STOREROOM LAYOUT.—When all of the above elements have been taken into consideration, it is possible to begin the planning of the storeroom layout. The following requirements must be fulfilled.

1. **Objectives:**
   a. **Materials held in the storeroom must be readily obtainable when needed.**
   b. **The layout should facilitate storage control.**

c. The layout should be as flexible as possible; i.e., it should be set up to permit changes and expansion with a minimum additional investment.
d. The proportion of aisle area to storage area should be as low as the above considerations will allow.

2. Dimensions of storage areas and bins. Size and proportions of the individual areas in a storeroom will affect (a) the proportion of aisle area to storage area and (b) flexibility of the arrangements.

The dimensions of the storage areas should be multiples of unit dimensions. For example, if unit dimensions are 3 x 5 ft., and another unit which might be stored in the same area has dimensions of 4 x 7 ft., a storage area depth of 11 ft. would always have some unused space, but a depth of 12 ft. would provide efficient accommodation for both items. Economical use of storage areas is thus secured. The position of the bins is another important factor. If the long dimension of the bins, or of stored cartons in a floor area, is perpendicular to the cross aisle, the ratio of bin area to aisle area is increased over an arrangement whereby the long dimension is parallel to the aisle.

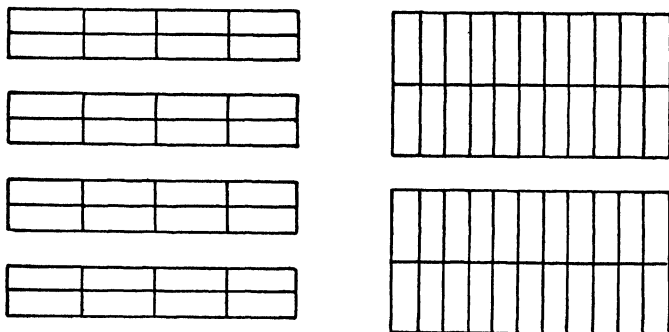



Fig. 20. Good Layout of Aisles in a Storeroom

3. Aisles. The main aisle should run the length—usually front to back —of the storeroom, from receiving point at one end to distributing point at another, unless the location of these points dictates some other arrangement. Adequate width, usually 5 to 10 ft., should be provided to avoid traffic congestion. Large storerooms often require subaisles parallel to the main aisle at distances of about 20 ft.

Cross aisles perpendicular to the main aisle provide access to bins or racks and to separate self-supporting piles of the large items. The size of the storage areas will determine the number of cross aisles. These aisles need be wide enough to accommodate one-way traffic only, and allow sufficient space for loading and unloading (see Fig. 20).

4. Distributing counter, desk and files. The storeskeeper's desk and files can usually be located next to the distributing counter, near the issuing window, rather than in an office in another part of the room.

5. Table space. Tables located near the distributing counter are convenient for a multitude of purposes: inspection, temporary storage, sort-

ing, weighing, and many minor kinds of work. Tables for inspection and unpacking should also be provided at the receiving point.

6. Location of items within the storeroom. The principles considered on preceding pages of this Section will govern allocation of items to different racks and bins.

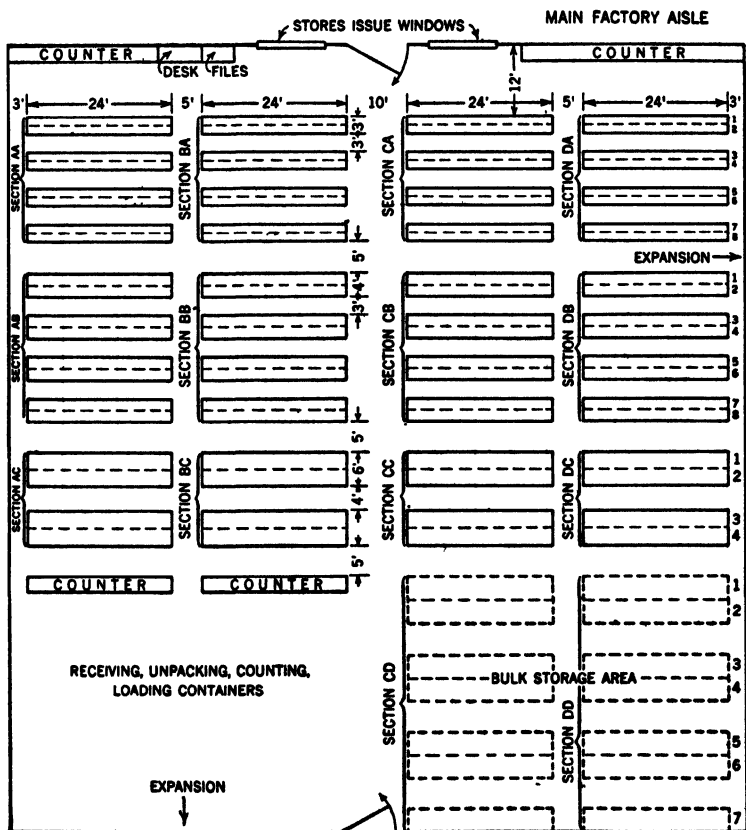



FIG. 21. Typical Method of Storeroom Layout and Section and Row Symbols

7. Area for unpacking, inspection, and temporary storage. During rush hours, materials may be received faster than they can be unpacked and placed in proper bins. Sufficient area should be provided in the storeroom to avoid congestion because of this condition.

8. Symbols for sections, rows, and bins. The numbering or marking system for the sections, rows, and bins should start at a permanent corner and increase in the direction toward which there may be storeroom expansion. Letters and numbers may be used alternately, letters being more convenient for sections and columns or stacks and numbers for rows and tiers. Corresponding stacks or bins should be given corresponding designations. A standard system should also be followed for labeling subdivisions of bins or stacks throughout the system. For example, if one bin in a row should be omitted for some reason, its number should be omitted in order to preserve the regularity of notation. Fig. 21 shows a typical storeroom layout with sections and rows marked. Fig. 22 shows the correct method of designating bin columns and tiers.

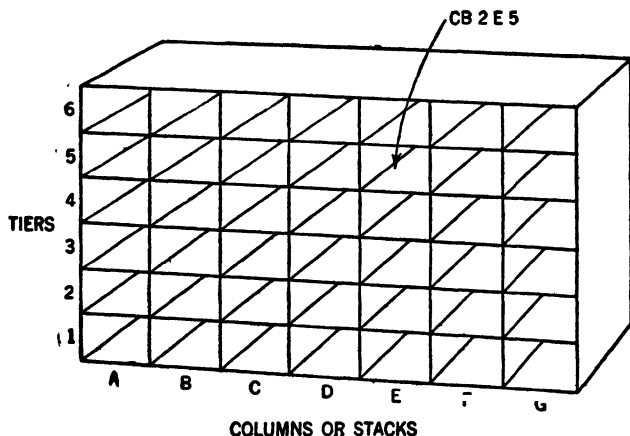



FIG. 22. Method of Designating Bin Columns and Tiers by Symbols
(Section CB, row 2, column E, tier 5)

In the Warner & Swasey Co., the section, aisle, and bin systems are laid out on a basis different from that described above, as shown in Fig. 23, which is a small portion of the location index used by this company.

The index is kept on Remington-Rand Linedex equipment, inserts consisting of laminated paper and wood strips glued to a kraft backer. The strips are typed on an ordinary typewriter and then removed individually or in groups from the kraft backer for insertion in the frames, which in this case are 20 in. high with 6 x 1/4-in. inserts. The record is kept in the receiving department.

The equipment is used also for control purposes. Whenever shortages occur on any stock item, a Linedex strip is set up on a separate record, filed by part number. When items are received, this record is checked before the material is sent to storage, thus permitting "back orders" to be shipped without delay and with a saving in handling costs.

No.	Description	Sec.	Aisle	Bin
3001	Cylinder Head	18	B	28
3002	Cylinder Head Gasket	7	D	19
3003	Cylinder Head Cap Screw	21	F	5
3008	Cylinder Front Cover	3	C	15
3012	Cylinder Cover Felt	14	A	38
3017	Time Gear Cover Gasket	6	L	12
3018	Time Gear Cover Plate	16	G	42
3020	Piston	5	B	11
3021	Piston .003" Oversize	27	M	4
3022	Piston .010" Oversize	11	D	34
3024	Piston .020" Oversize	8	B	42
3025	Piston Pin	13	F	18
3027	Piston Ring	23	B	19
3030	Connecting Rod	6	A	15
3031	Connecting Rod Cap Bolt	14	G	21
3035	Connecting Rod Clamp Screw	6	A	34
3040	Crank Shaft	9	H	10
3041	Crank Shaft Gear	15	B	6
3053	Crank Shaft Starting Pin	2	A	14
3055	Crank Shaft Bearing Cap Stud	22	E	2
3061	Cam Shaft	8	B	11
3063	Cam Shaft Front Bearing	12	C	9
3064	Cam Shaft Center Bearing	7	E	10
3065	Cam Shaft Rear Bearing	2	A	17
3066	Cam Shaft Bearing Ring	1	F	5

FIG. 23. Stock Location Index Board

Protection of Stores

NEED FOR PROTECTION.—An important part of every storeskeeper's job is to protect stores from fire, rust and corrosion, deterioration, evaporation, dust, theft, weather, heat, cold, and moisture. Each kind of material requires its own kind of care. Briefly, the considerations to be met in each of these situations are as given below.

Fire.—Adequate fire-fighting apparatus should be installed and readily available. The equipment necessary consists of high-pressure water lines with connected hose lines, a modern sprinkler system, hand extinguishers with chemicals suitable for the kinds of materials stored, fire pails, sand, axes, and, for outdoor storage, fire hydrants, hose carts, and perhaps ladders. In installing the sprinkler system, sufficient properly located heads should be provided, and the articles stored beneath them should not be piled so high as to prevent water from spraying directly on the lower bins or layers where fires usually start. Inflammable materials should not be allowed in the storeroom. Gasoline, powder, dynamite, and the like should be situated in outside isolated, fire-resisting buildings, or in underground storerooms.

Cleanliness should be the watchword. Oily rags and other substances subject to spontaneous combustion should be disposed of immediately.

The aisles and passageways should be kept clear to facilitate access to any place where fire may break out or spread.

Rust and Corrosion.—Machine castings and forgings, and other material subject to rust and corrosion, must not only be stored in dry places but also in some cases slushed in heavy oil or covered with grease to prevent rust.

Deterioration or Evaporation.—Materials which deteriorate or spoil through age must not be overstocked. Rubber products, for example, will dry, harden, crack, and break with age or if subject to heat or cold. They must be stored in such a way that they will be used in the order of their receipt, that is, first in, first out. The duplicate-bin system is most useful in the case of such materials. Volatile materials and liquids which evaporate must be kept in tightly closed containers.

Dust.—Materials which are spoiled if soiled by dirt or dust should be protected by enclosure in boxes or storage in closed cabinets. Typical of these materials are finished textile goods and stationery supplies.

Theft.—Employees are prone to help themselves to articles which would be handy for home or personal use. Unfortunately, this practice is not regarded as theft, but it still constitutes both a loss of money and possible delays in production where the occurrence is flagrant. Physical inventory shortages sometimes make considerable difference between profit and loss in a manufacturing concern. To avoid losses from petty theft, it is necessary to keep materials in a closed storeroom at all times, to store the more valuable articles in locked cabinets or even in a safe, and to insist upon the presentation of a proper requisition for all withdrawals for any purpose.

Weather.—Materials whose bulk and nature demand that they be stocked out of doors can be protected from the elements by building open sheds with roofs to keep them from getting rained on, or buried in snow. Steel shapes and bars, lumber, and drums and barrels of chemicals are in this category.

Heat and Cold.—Liquids or materials whose character would be affected by changes in temperature must be kept in air-conditioned rooms, those spoiled by possible freezing, in heated areas, and those subject to deterioration if exposed to high temperatures, in cool areas.

Moisture.—Materials and supplies should be protected from pipes which may sweat and drip because of conditions of air humidity and room temperatures.

Storeroom Operation and Records

WORK OF THE STORESKEEPER.—The duties of the storeskeeper are to:

1. Receive materials, checking to see that the kind, count, and conditions are as indicated.
2. Place them in the proper locations in stores.
3. Enter their arrival on the records.
4. See that they are protected from loss or damage.
5. Issue them to the respective users or departments upon duly authorized stores issue requisitions.
6. Record the withdrawals and enter the balance on hand of each item.
7. Make periodic and systematic check counts to verify the balances and report such counts to the stores record or materials control section of the production control.
8. Be on the alert to report approaching shortages which may have escaped notice by the stores record section.
9. See that the storeroom is kept clean and in good order and that all items are put in their proper places and kept there.
10. Train and supervise the storeroom employees.
11. Try to improve storeroom operation, layout, and service and coordinate the work with that of other departments.

STOREROOM RECORD-KEEPING.—Records found in every storeroom are those used to keep up-to-date inventories of stored materials and those used to facilitate storeroom operation and control. The basic factors in storeroom record-keeping may be stated as follows:

1. Responsibility for storeroom records should be centralized; i.e., all records and forms relative to stores received and issued, as well as storeroom bin tags (see Fig. 24) or inventory cards, should be tied in with the materials control section of the production control department. This same principle should be followed even when storeroom operation is quite decentralized.
2. Record-keeping for individual storerooms should be made as simple as possible. There should be a minimum number of forms used, and these should demand only a minimum amount of clerical work.
3. The storeskeeping record system should be linked with cost and accounting records; i.e., provision should be made to route stores forms to both the cost accounting and general accounting departments.

RECEIVING AND ISSUING MATERIALS.—When incoming materials have passed receiving inspection, they are ordinarily delivered to the storeroom with a copy of the receiving report. If parts are made in the plant and stored, they will come to the storeroom with a materials-delivered-to-stores form. In each case, after the storeskeeper is satisfied as to kind, count, condition, and the fact that they are to go into stores, the materials are put away and an entry is usually made on a bin tag (Fig. 24) showing how much was stored and the balance then on hand. The storeskeeper then will notify the stores record section of the receipt —often reporting the new balance as a check. When material or stores

issue forms are submitted to the storeroom for withdrawal of materials by individuals, truckers, or materials men, the storeskeeper will see that the orders are filled, deductions are made from bin tags, new balances calculated, stores issue forms are initialed, and the latter are sent to the stores record section for posting to the central control records on the perpetual inventory sheets. Sometimes the balance remaining is entered on each stores issue form as a check with the stores records clerk. If the storeskeeper notes that certain balances seem unsafely low according to records of current use, he should report the fact specially, or on the form, to the stores record section. Also, he will often be called upon to verify a count at the request of this section. In fact, a regular program of checking counts on a standard procedure is frequently followed—impor-

BIN TAG ITEM ______			INVENTORY NO.,		
DATE	ORDER NO.	IN	OUT	BALANCE	SIG.

FIG. 24. Bin Tag

tant materials every month or two, less important items two or three times a year, remaining items at least once a year. Under this plan there need be no annual physical inventory, the inventory being perpetually in proper balance. It is the function of the stores record section in most cases to place purchase requisitions for replenishing stocks of items approaching the order point.

In some cases simple stores record cards showing merely receipts, issues, and balances are kept in the storeroom by a special clerk. This method may eliminate the bin tags. Duplicate records in the one place are unnecessary. Occasionally, but not frequently, stores record-keeping and the actual storeskeeping are both done in the storeroom. The preferable method is to have the records in the production control department where they are needed for the planning of production and coordination with the operating activities of the plant.

SECTION 7

TIME STUDY AND OPERATION ANALYSIS

CONTENTS

Fatigue in Factory Operation

Analysis and Synthesis of Job Data

Standard Data Method

Complex Time Studies

Work Assignment Illustrated

SECTION 7

TIME STUDY AND OPERATION ANALYSIS

PROCEDURE IN TIME STUDY AND OPERATION ANALYSIS.—Time study, operation analysis, and job standardization divide into:

Preliminary. Recording and analyzing existing conditions as to process, equipment, arrangement, material handling, etc., to determine whether best and least fatiguing methods are being used.
Collection of data. Breaking down the operation into elementary operations or motion elements.
Analysis. Critical study of these "elements," discarding those that are useless and inefficient, and improving others until they are best obtainable. This step includes improvement of methods, tools, and workplace. It usually involves study of motions and time alternately.
Synthesis. Putting together these improved "elements" into the best combination, and fixing their base times.
Allowances. Determining allowances for necessary delay and for fatigue.
Write-up. Standardizing all findings by reducing them to some form of written standard practice. Drawing up detailed instructions covering tools necessary, elementary operations involved in detail and in proper sequence with time allowed for each.
Application. Training workman to perform the task in the manner and time set.
Control of conditions. Maintaining requisite working conditions, equipment, and supply of material.

DETAILED VERSUS SHORTER METHODS.—In this section the underlying theory and statistical aspects of time study work are presented in sufficient completeness for a correct and adequate understanding of the subject. In established time study departments, while these aspects remain fundamental, numerous shortcuts and special techniques are developed for use where complete studies would not be justified, and these shorter methods are the ones in frequent use. It must be remembered, however, that such methods depend on the established data of particular companies, and should be used only by experienced time study men who fully understand the qualifications and limitations.

Definitions

OPERATION ANALYSIS.—Studies of the entire process may be made to determine whether operations can be eliminated, combined, or the sequence changed. An operation analysis is made of method, mate-

rial, tools, equipment, layout, working conditions, and human requirements of each operation to determine the "one best way." Training the operator in the improved method is an essential part of operation analysis.

A FAIR TASK.—Job standardization is more than timing with a stop-watch. Taylor (Trans. A.S.M.E., vol. 34) said: "Mere statistics as to time which a man takes to do a given piece of work do not constitute a time study. Time study involves careful study of the time in which work **ought** to be done." It is an analytical study of methods and equipment used, in which timing is only a part. Neither is it a mere "speeding up process." It seeks to **develop the one best way** of doing work. This results usually in shorter time, but seeks it by the use of improved methods and elimination of wasted energy, not by overspeeding the worker. A task which results in the immediate or gradual exhaustion of the worker has been wrongly set. Proper job standardization usually locates the task high but not above what a normal operator can do steadily and do happily.

Rates of production or tasks resulting from operation studies are often so high as to meet, at first, with incredulity and opposition from workmen. It is becoming increasingly desirable to all concerned, however, that tasks be measured according to standards which are accurate and fair. Management must be prepared to demonstrate the possibilities of tasks, and to **teach workman** how to perform in the time set, also to guarantee his wages during the period of learning.

Quality of product must be protected through inspection because the setting of task standards always stimulates workers to increase the quantity of production. Quality, however, must be made the prerequisite to quantity. When inspection is adequately stiffened, standardization will maintain rather than lower quality. Another advantage is that **time and piece rates can be set which need not be cut.**

Job and methods standardization is **essential to labor cost control** and so is a vital activity in any industrial operation. A knowledge of the principles on which this form of standardization is based, and the techniques whereby it is achieved, is necessary to both cost and operating executives.

JOB STANDARDIZATION.—

Job standardization consists in determining the one best way of performing a job, under the means at command, of recording the exact method on an instruction card together with the time that each elementary operation should take, and establishing means to maintain the standard conditions.

Standards once established should not be changed so long as the method of performing the job remains unchanged. It frequently happens that new tools, fixtures, or machines are designed for a standardized job, in which case it is obvious that the standard conditions surrounding the job will have been changed and the original standard can no longer apply. A new standard must then be set up to supersede the original standard.

Historically there were two distinct procedures for deriving job standards, one called "time study" and one "motion study."

TIME STUDY.—Time study is defined as:

A searching scientific analysis of the methods and equipment used or planned in doing a piece of work, development in practical detail of the best manner of doing it, and determination of the time required.

The first result of this procedure, when sincerely followed, is finding that minor operations are duplicated in many different major operations. Hence it is possible to standardize such elementary operations and to utilize these in any desired combination, reducing thereby the amount of subsequent study necessary to cover the whole range of work.

To realize standard performance so determined in actual production, Taylor found **three additional factors necessary:**

1. Careful instructions to, and training of, workmen. These instructions, corrected, tested, and written, constitute permanent records of best practice.
2. Extra incentive over prevailing day wage is necessary.
3. The management must undertake to set up and maintain conditions of equipment and flow of material vital to performance.

ELEMENTS OF AN OPERATION.—Elements of an operation are a series of motions, in a work cycle, which can be definitely recognized, described, and recorded.

Job Study

MOTION-TIME ANALYSIS.—The object of motion-time analysis is to eliminate lost time by training workers to do their work the right way, by improving methods and equipment, and by providing management with correct standards of both methods and time on all operations, as a means for supervisory control.

Basic principles of the Segur plan of motion-time analysis are:

1. All work can be subdivided into 17 fundamental motions, or "therbligs."
2. Within practical limits, the times required of all expert workers to perform true fundamental motions are constant. Motion-time analysis provides the means for finding the right motions and the right time to do any operation. It does this quickly and directly
   a. From observation.
   b. From established formulas and tables.

Rules of Motion-Time Analysis.—Segur gives six rules to be followed in taking time studies:

1. Before taking the time study of any job, try to **put yourself in the position of the man** who is going to do the work. Learn the shortcomings and write down the description of how you expect the job to be done. Include this description with your time study. When starting the operation, under incentive, be sure the operator who is doing the work can do it according to the method as you have laid it out, and is actually doing so.

2. Remember, it is just as important to know **what an operator is thinking about,** as it is to know what an operator's hands are doing. Always determine where an operator's eye must be used, and determine whether an operator actually does use his eyes. Study the material to

determine what mental processes will be required on the part of the operator when performing the operation as you have laid it out.

3. **Watch for unusual features of the material.** Does the material hurt the hands when picked up? Is it extraordinarily heavy? Does the table tire the operator? Does the machine have any peculiarities that the operator should know about?

4. Remember the operator is not paid on how you think the job should be done; the operator is paid on how the job is done. If the job is not done actually the way you think it should be done, then you must **time it as the job should be done.** You are entitled to call the attention of the management to the losses which occur due to faulty methods of operation.

5. Remember that machine, chemical, and physical **processes do not take place instantaneously.** Glue does not take its set the instant that it is touched to another piece of glue. The punch press does not operate as soon as the operator touches the release pedal with his foot. It takes time for a drilling machine to cut through a piece of steel. Therefore, it is important that you take account of all these times in your thinking and in your time study as well.

6. Good methods of doing the job are useful in so far as you are able to **teach these good methods** to the operator in question. A method may be ever so good, but unless you can transmit the information accurately, you are not entitled to take advantage of it in your study.

CHOICE OF OPERATION ELEMENTS.—Operation elements as short as .03 min. can be recorded accurately by the experienced analyst, using a stop watch, and .02 min. if separated by longer elements. These short elements are more useful when analyzing studies, building new standards, and checking other studies. However, elements of .05 min. to .09 min. are more accurately recorded, as the analyst has longer time to observe the operator's movements. Using a time study machine (Marstochron) elements of .01 min. and possibly shorter can be recorded accurately.

DISTINCTION BETWEEN TIME STUDY AND MOTION STUDY.—In motion study, work is divided into the most fundamental motions, the usual micro-chronometer recording readings to .0005 min. In time study, work is divided into "elements" as short as .01 min., using the time study machine, or as short as .02 to .03 min., using the stop-watch. In either case useless motions should be eliminated, and combinations and sequences of motions improved. In motion study **the one best way** is determined and operators are trained to follow this method. In time study the best method is also determined, but emphasis is placed mainly on setting standards for cost purposes, wage incentives, production standards, etc.

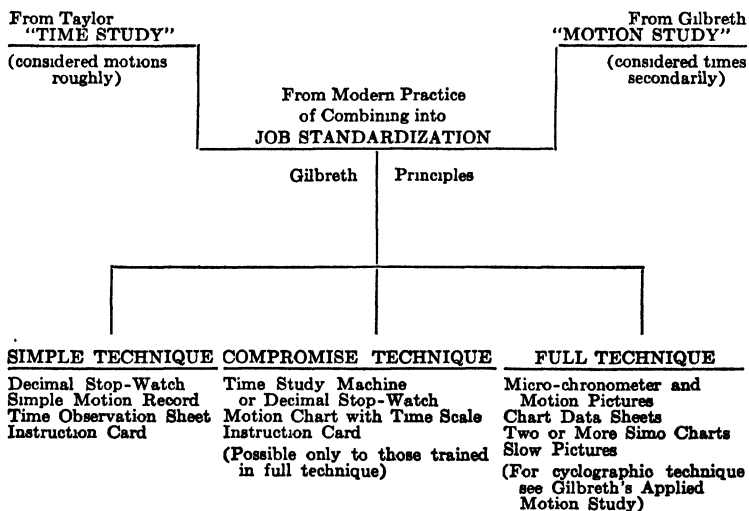
JOB ANALYSIS.—Job analysis is:

> Determination of the essential factors in a specific kind of work and of the qualifications of a worker necessary for its component performance. (Hackett)

It can be carried on independently but is most reliable when combined with a program of job standardization. Job analysis does allow classification of jobs but is sometimes used as a basis for incentives.

This basis as commonly used is crude and suitable only for jobs difficult to standardize, such as general office duties which are not specialized.

THREE TECHNIQUES OF JOB STUDY.—Studying of production jobs can be carried on: (1) by simple motion study and measurements with stop-watch in the shop; (2) by micromotion study and measurements with motion picture camera, micro-chronometer, etc., in the laboratory; or (3) by a compromise between techniques (1) and (2). The term **time study** was narrowed by some practitioners to cover only stop-watch procedure, and **motion study** to cover the photographic procedure. These interpretations are no longer significant, as both time and motion study are essential in some form, and characteristic of all three techniques. Many jobs not to be often repeated are in practice put on incentive rates with very sketchy "time study," but this practice is hazardous. The **breakdown of work** under all techniques is similar, until fundamental elements or therbligs are reached.

RELATIONSHIP OF TERMS

The elements in the two procedures compare as follows:

Stop-Watch Procedure	Micromotion Procedure
1. Process or departmental job.	1. Process or departmental job.
2. Operations.	2. Operations.
3. Elementary operations or cycles of motions.	3. Suboperations or cycles of motions.
4. Motions (can and should be studied to some extent but not timed).	4. Therbligs.
	5. Variables.

A more detailed comparison of the factors is given in the following analysis:

Stop-Watch Procedure	Micromotion Procedure
1. Requires less elaborate measuring equipment.	1. Micromotion records nearly all conditions which affect work, excepting sound, and that could be recorded if important.
2. Requires less highly specialized experience as prerequisite on the part of the analyst.	2. Records do not lose independability as time passes. It is possible to pick out, study, and regroup elements at any time without repeating performance.
3. Is easier to use in the shop.	3. Emphasis is placed on method, time being a by-product.
4. Attracts less attention and creates less disturbance. Therefore there is less need for a special motion study laboratory.	4. Time and motions are recorded automatically and more accurately.
5. Is sufficiently accurate and adequate for many practical purposes, particularly if the analyst has been trained in micromotion.	5. Films and models, visual records of best practice, may be made for teaching.
6. Gives sufficiently reliable record for many purposes if simple motion study is properly made.	6. Records provide a permanent basis for accurate comparison and study, not approached by any other method.

COSTS OF JOB STANDARDIZATION DIFFICULT TO ESTIMATE.—If the cost of job standardization could be known in advance for both of the extreme procedures, the problem of choice between them would be simple but such costs cannot be estimated accurately in advance for any study in question. Costs gathered from completed studies within a single department may be used as guides to costs of further studies by the same staff, but considerable uncertainty would remain because it is never possible to know where a new study will lead or how far it will extend. Studies by ordinary stop-watch technique are least likely to ramify or to cause radical changes and for this reason can be most closely estimated in cost. Studies by full micromotion technique are most likely to cause real upheaval and in any case are most expensive. The **choice between these extreme techniques** is therefore by common sense dependent on the scale or volume of product going through any given operation, and the volume has so far been placed exceptionally high to justify the full measuring technique. Perhaps, due to fears or even to ignorance as to what is involved, this limit has been higher than would prove economical. Gilbreth always denied any excessiveness in the cost of full micromotion relative to results.

PROCEDURE MUST BE STANDARDIZED.—The strictest standardization in procedure is necessary for the analyst if the results of different studies are to be compared. Even with a single analyst, data

can be made valueless by the lack of fixed technique. Unstandardized technique is hopeless where several analysts are working together. Blanks covering all requirements should be designed and ready before any studies are made, otherwise important items may be forgotten and no two studies will agree in arrangement.

MOTION STUDY OF SOME SORT IS INDISPENSABLE.—A wide range between good and bad practice is possible, particularly in stop-watch procedure. Results depend upon how thoroughly governing conditions are noted and recorded. Advocates of micromotion claim it is impossible for the time study observer to make a written record of motions and surrounding conditions which will have any permanent value. Under some conditions this is true. However, if the operation is fairly simple and the analyst skilful, a sufficiently good descriptive picture can be recorded. **Short symbols and words** can be selected in advance to stand for complex happenings, as, in stenography, symbols stand for complex expressions. Use of such symbols should be practiced by the observer until every important activity can be rapidly recorded. When sufficient skill has been developed by the analyst, actions can usually be recorded as fast as they occur. Later records can be transcribed in regular language. All essential surrounding conditions should be entered on the records. Sketches and pictures should be used freely when these are helpful. By dividing the analysis sheet vertically, one side can be used for motions of the left hand, and the other for those of the right hand. When both hands are used, entry can extend across the central dividing line. Fig. 1 shows a **simple motion study** of a short sewing-machine operation where the "preparation" group, items 1 to 11, occurs only once, and is separated from the machine running cycle, items 12 to 26, which is used with each garment. The "completion" group, items 27 to 31, is similarly separated. In **using the sheet for instruction purposes** it was found advantageous to fold the machine cycle, items 12 to 26, out of sight until undoing and replacing of the bundle was mastered, thus breaking the lesson down into two simple tasks. Handling of bundles can usually be standardized throughout the factory no matter what the machine cycle may be. This type of motion record is simple to use and makes it possible to do work superior to that possible through the average stop-watch practice. It does not, however, get down to therbligs, nor allow detailed analysis. In fact, it requires a separate form for time observations.

PORTIONS OF MOTION AND STOP-WATCH STUDY COMBINED.—Fortunately most, if not all, of the benefits of full micromotion procedure can be secured without its measuring technique, provided the analyst has been trained under that full technique and has thereby learned how work methods can be radically improved; that is, how to recognize all such opportunities and best solutions. No amount of experience in stop-watch procedure and no amount of book study on micromotion procedure can qualify an analyst for fundamental work in this field. The **greatest value of full micromotion technique** lies, not in its full application to the few jobs needing exceptional improvement, but in its use as a means of training the job analyst. When he is so trained it is of secondary importance whether his synthesized steps

THE BLANK UNDERWEAR CO. No. 1. PLANT

Motion Study—Observation Sheet

OPERATION—Collar Seaming	DATE—
OPERATOR—W. P.	TIME—9:00 to 11:00 A.M.
DEPARTMENT—Finishing	GARMENT—Reg. Light Weight Union Suit
OBSERVER—C. W. L.	MACH.—Union Special

No.	Left Hand	Both Hands	Right Hand
1.	Turn bundle right side up		
2.		Lift bundle to lap with necks at left and straighten	
3.		Untie cord	
4.	Pull out cord		Hold back garments
5.	Hold ticket		Sign ticket
6.	Hold ticket		Clip ticket
7.		Open bag	
8.	Hold bag open		Take out collar and lay on table at right
9.	Hold bag open		Take out back pieces and lay on table at right
10.		Shirr up bag	
11.		Lay bag on table at left: cord ready for bundle	
12.			Pick up garment
13.		Open top part	
14.		Place on machine left front corner ahead	
15.	Hold garment		Pick up one back-piece
16.	Hold garment		Pick up one collar
17.	—first one only—hold end of collar.		Fold other end over to test marks
18.	Place collar on garment and hold		Hold garment
19.		Feed and guide to second mark, first mark at seam	
20.	Hold garment		Put in back piece from under side
21.	Bring collar even		Fold back piece
22.		Feed and guide to come out even	
23.	Break thread		Hold garment
24.	Lift garment		Take it by middle
25.	Fold in the middle		
26.		Lay on table over cord	
27.	Pick up ring end of cord		Pick up free end
28.	Hold ring		Put free end through ring
29.	Hold bundle		Pull cord through ring
30.	Hold ring and cord		Loop and tie
31.		Lay bundle aside	

FIG. 1. Simple Motion Study of Collar Seaming

are accurately measured or not; whether they are always recorded on a film or not, because he will have recognized every opportunity for improvement and will have utilized the best existing solutions. Gilbreth insisted that to a properly trained analyst time was of secondary importance as compared with methods improvement through motion study.

EXAMPLE OF "COMPROMISE TECHNIQUE."—It is impossible to convey briefly any example of the thinking and training which must precede the use of this technique. On the basis of such training, however, the technique is little more than that of simple motion study

FIG. 2a. Bench Layout—Old Method

Solder pot
Knock-off plate
Flux pot
Supply pan
Finished stock

Total time per cycle .12 min.
Total time per unit .12 min.

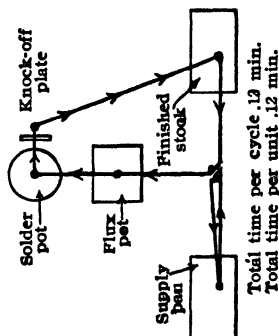



FIG. 2b. Motion and Time Record—Old Method

OPERATION ANALYSIS AND SYNTHESIS SHEET

PART NO. *X-10001* PART NAME *Terminal Block Assembly*
OPERATION *Tin dip terminals*
SEQUENCE: ORIGINAL OR ~~DEVELOPED~~. SHEET NO. *1* OF *1* SHEETS
DATA FROM TIME STUDY NO. *2606* ANALYST *E.H.M.* DATE *10/12/—*

LEFT HAND	MINUTES	RIGHT HAND
Pass Block to Right Hand		*Receive Block from Left Hand*
Pick Block Up		*Dip Terminals in Flux*
Hold Block	.05	*Dip Terminals in Solder Pot*
	.10	*Shake off excess Solder*
		Toss Block into Stock Pan

OPERATION ANALYSIS AND SYNTHESIS SHEET

PART NO. *X-10001* PART NAME *Terminal Block Assembly*
OPERATION *Tin dip terminals*
SEQUENCE: ~~ORIGINAL~~ OR DEVELOPED. SHEET NO. *1* OF *1* SHEETS
DATA FROM TIME STUDY NO. *2606* ANALYST *E.H.M.* DATE *10/12/—*

LEFT HAND	MINUTES	RIGHT HAND
Pick Block Up		*Pick Block Up*
Dip Terminals in Flux	.05	*Dip Terminals in Flux*
Dip Terminals in Solder Pot		*Dip Terminals in Solder Pot*
Shake off excess Solder	.10	*Shake off excess Solder*
Toss Block into Stock Pan		*Toss Block into Stock Pan*

FIG. 2c. Motion and Time Record—New Method

Solder pot
Finished stock
Knock-off plate
Knock-off plate
Flux pot
Supply pans

Total time per cycle .13 min.
Total time per unit .065 min.

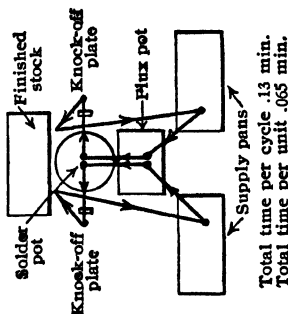



FIG. 2d. Bench Layout—New Method

with the stop-watch or time study machine. Use of a decimal time scale with description of simultaneous motions avoids the need of separate observation records and permits both analysis and synthesis. The Western Electric Co. published such a study of a one-man soldering job (Fact. Mgt. & Maint., vol. 83). Fig. 2a shows a bench layout or symbolic plan view of the old motion path used on this job. The left hand did little more than hold the block while the right hand did most of the useful work. An **analysis and synthesis sheet** was made out for this old method, Fig. 2b, in which the same unbalance is shown against a stop-watch time scale. This central time scale allows not only time measurement of the elementary operations but also comparisons of such measurements as between the two hands. Note the horizontal line inserted at the end of each elementary operation. Analysis and synthesis from these two charts, according to Gilbreth principles, brought about the improved charts Figs. 2c and 2d. **Making two units simultaneously** made it possible to utilize each hand equally and oppositely. This new two-unit cycle, only .01 min. longer than the old one-unit cycle, reduced time per unit 46.8%, increased production 84.6%, and reduced total cost materially.

Bench arrangement was radically, but not expensively, changed. At first thought it would seem possible to make such bench improvements without analyzing and synthesizing motions, but experience shows that this cannot be done. Only by considering motions in the light of principles can ideals of bench arrangement be seen.

Introducing Time Studies

LABOR'S REACTIONS TOWARD TIME AND MOTION STUDY.—Spencer Miller, Jr. (Mech. Eng., vol. 60) states that, in the past, the opposition of unions to time and motion study has arisen from the fear that possible transfer of skill would make them weaker and more dependent on management. Once the worker feels that such is neither the aim nor the result of time and motion study, his criticism turns to the methods used for making these studies rather than the principle. "Union labor, however, is sensitive to the harmful speeding up of workers or to the introduction of any managerial method or device that might be used in this direction." It is suspicious of piecework, basing this suspicion on a heritage of unscientific rate setting and sweatshop days. Time study is still regarded among some unions as just another adjunct to forcing the last ounce of effort out of workers at the smallest possible cost in wages, instead of which "**time study should be a scientific method of measuring human effort** and productivity in terms of time." In many instances, time study methods have been imposed without the consent of the worker or the benefit of joint review. "Also, little recognition has been given to the fact that it is the worker's job and health, indeed his very life, that will be affected."

TIME STUDY IN UNION SHOPS.—Time study has been successfully conducted in many union shops, with the full cooperation and consent of unions and workers. A pioneer example, in New York City, was in the garment trades, in which a board of control was organ-

ized for the Dress Manufacturers' Association and the International Ladies' Garment Workers' Union.

A "test" shop was established, and operations on a large number of blouses were studied, chiefly by the union's industrial engineers trained in time study. Unit times were established for operation elements, so that by proper combination of these elements, standard times could be established for making a blouse of any style or material. Standard times of these elements would vary; for instance, the time per 1/4, 1/2, 3/4 yd., etc., for stitching was given a different value for each kind of stitch and seam, and different values were set for straight and for curved stitching. For each of these, in turn, different values were given for different kinds of fabric. From these data it was possible to set up standards applying to different conditions in different shops. Thus it was possible to predetermine the **standard time to make a garment** of any style and materials.

With standard times determined, the problem of piecework prices resolved itself into a question of hourly earnings. There was no haggling on individual piecework prices.

CHANGES IN LABOR'S ATTITUDE.—Labor has begun to recognize the superiority of scientific time study, as a measuring device, over any less accurate method of time measurement. "General acceptance of time study by labor, however, will be won only on the basis of frank conference between management and union, in which the method to be used and its objectives are discussed beforehand and labor's consent and cooperation invited. This is the method which was pursued successfully in each of the cases referred to." (Miller, Mech. Eng., vol. 60.) Under such method of union-management cooperation, unions will know that their members are safeguarded against harmful speed-up and excessive effort, they will participate in improvement of their own jobs, have a protected contractual wage scale, and will share equitably in any savings which follow the time studies. With these prerequisites accepted by management and with a better knowledge on labor's part of the usefulness of time study, increased acceptance by labor will doubtless follow, and be incorporated in collective agreements.

COOPERATION IN THE STEEL INDUSTRY.—The Steel Workers Organizing Committee has several examples of time study installations. Those which they consider to have been handled in a satisfactory manner are indicated (Golden and Ruttenberg, Adv. Mgt., vol. 7):

> At the ABC Steel Company, the union was consulted before the company made any decision on incentives. A detailed explanation was given and a common understanding was reached. For the past two years four union members, including the secretary of the local union, have been working in the time study department. All standards are checked and agreed upon before they are put into effect. After a trial period a recheck is made if the standards are unsatisfactory. The time studies and standards are an open book and can be inspected by all interested parties.

HOW TIME (AND MOTION) STUDY IS APPLIED.—To determine how time and motion study is being applied in industry, a questionnaire was sent out by Hummel (Mill & Factory, vol. 19) to 75 companies believed or known to be using motion and time study. Replies

were received from 50 companies, both large and small, located in all parts of the country.

One question asked was: "Do you improve and standardize equipment and methods of doing work before making time studies?" Replies to this query were: Yes, 88%; No, 12%. The comment received from one concern is interesting: "The main idea is to improve labor utilization of equipment already in use without large outlay for new machinery or equipment." The following comment was received from another company: "We improve and standardize equipment and methods, but improvement is frequently the result of motion and time study."

Two other questions inquired as to the purposes of time and motion studies, and the use of elemental operations in taking time studies.

The one, recorded with the percentage of answers, was as follows: "For what purposes do you use results of time and motion study?"

Purpose	Percentage of Firms Replying
1. As a means of reducing cost	100
2. As an aid in the accurate determination and control of labor costs	95
3. As a basis for a wage incentive plan	91
4. As a basis for time estimates on future work	86
5. As a means of balancing working force with available work	84
6. As an aid in planning production	79
7. As a means of improving quality	65

The other question was: "In taking time studies, do you divide the work into the shortest possible elemental operations which may be accurately time studied?" The answers were: Yes, 93%; No, 7%.

The importance of each of the six factors which are often the basis of allowance percentages was brought out by the following question which was answered by the percentages of firms as indicated: "If the addition of allowances is a part of the procedure in deriving a time standard, what things are regularly included in allowances?"

Regularly Included in Allowance	Percentage of Firms Replying
1. Fatigue	93
2. Unavoidable delay	83
3. Personal needs	76
4. Set-up or preparation operations	57
5. Irregular or unusual operations	38
6. Time required to learn	7

Frequently it is found desirable to have a separate standard for set-up. This is the case where the order or lot size varies appreciably from time to time.

It is recognized that the real incentive to employees is dependent upon the observation not only of the letter but also the spirit of guarantees of time standards or piecework standards. A question on this point was included in a questionnaire: "Are time standards guaranteed against change unless major changes in methods or equipment are made?" The answers were: Yes, 75%; Guaranteed definite time unless major changes are made, 14%; No guarantees, 11%.

Time Recording Equipment

SIMPLEST FORM OF STOP-WATCH.—The plain stop-watch (Fig. 3) is started by moving A toward the stem, and stopped by moving A away from the stem. Pressure on B brings the hand to zero. The watch has a single large hand making one revolution per minute, and a small one making one revolution in 30 min. The watch will continue on for runs of longer time than 30 min., but the number of 30-min. periods must be noted or checked from an ordinary watch. This type of watch is used more than any other for time study work. It is adapted to both continuous and snap-back methods of recording.

SPLIT-HAND WATCH.—The split-hand watch (Fig. 4) has two large hands. By successive presses of stop B, both hands will start together, stop, and return to zero. By pressing stop A, the lower hand is held wherever it is, while the upper hand continues its progress. This is done when a delay occurs so that its time may be read without interrupting the over-all timing. At a second pressure of stop A, the lower hand instantly catches up with the upper hand and continues with it. This watch is not adapted for snap-back recording.

Another variation is a series of numbers about the dial which indicate the number of times any elapsed time is repeated per hour. This feature is more confusing than helpful.

DECIMAL-HOUR WATCH.—A watch frequently used in time study work is the decimal-hour stop-watch (Fig. 5). The large dial is divided into 100 divisions. The large hand makes one revolution in 36 sec., or 1/100 of an hour, the small hand revolves once for each 30 revolutions of the large hand.

CALIBRATION OF WATCHES.—Stop-watches should be calibrated from time to time by operating them 15 min. and comparing their readings with a regular watch or chronometer of known reliability.

TIME STUDY BOARD.—The data or observation sheets, and usually the watch, should be held by a specially designed board. Movement of the stop-watch is more delicate than that of an ordinary watch and it should be handled carefully. If the analyst holds it in his hand, he is sure to lay it down occasionally, often on vibrating machines or benches where it is liable to accident. Moreover, it should be in a fixed position relative to the observation sheet. Therefore, the watch should be mounted on the board. A simpler arrangement is a home-made, three-fingered, brass holder screwed to the upper edge of an ordinary clamp filing board.

The time study board (Fig. 6) combines the features needed for general job standardization work. It provides a convenient writing surface for holding record blanks and holds the stop-watch in position to be operated by the left hand while the left arm supports the board, leaving the right hand free to record observations. The watch is held in a locked holder which gives protection against breakage, permits functioning at an angle to avoid glare on its face, and offers the maximum of visibility in use. Further, the shape of the watch holder provides a hand grip to assist in holding the board and increases the ease of handling

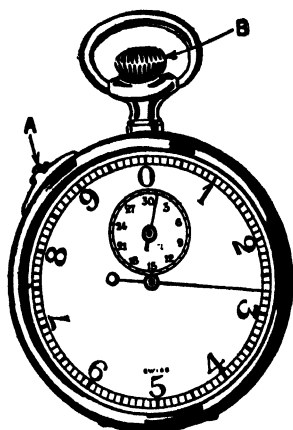



Fig. 3. Plain Decimal Stop-Watch

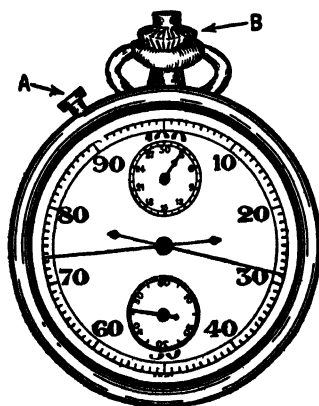



Fig. 4. Split-Hand Time Study Watch

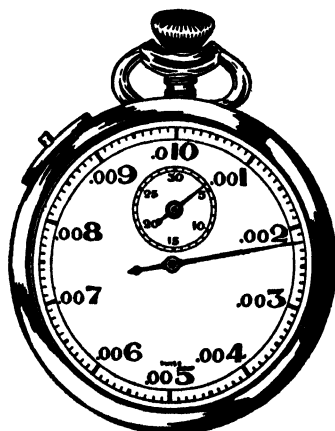



Fig. 5. Decimal-Hour Stop-Watch

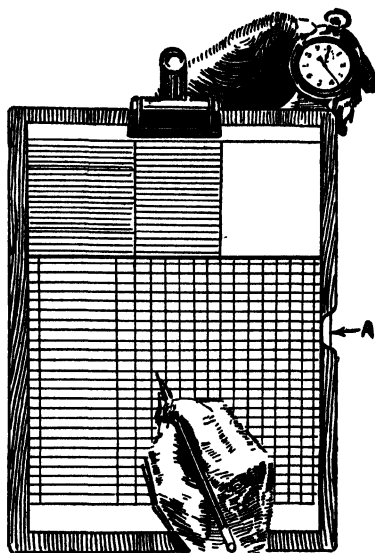



FIG. 6. Typical Design of Time-Study Board

the watch. The woodwork of the board is laminated to eliminate warping under reasonable treatment.

Some analysts also attach an ordinary watch to the board and even a duplicate stop-watch; the former is unnecessary and the latter is used only in special cases. An ordinary wrist watch can be used for the time of day, needed only at the beginning and end of each observation sheet. The technique should be as simple as possible to free the analyst for observing unexpected events.

Shaped boards have advantages for certain purposes. The size and design of the board vary in accordance with the forms to be used on it.

TIME STUDY MACHINE.—When it is necessary to record shorter time intervals than those obtainable with the ordinary stop-watch, a time study machine, Marstochron (Fact. Mgt. & Maint., vol. 97), may be used, by means of which times of .01 min. and less, can be recorded. The beginning or end of the operation is recorded by pressing two keys, the end of each element by pressing one key. The observer does not have to take his eyes off the operator and there is nothing to write down. Pressure on either key depresses a type bar making a mark on a tape, which moves at the rate of 10 or 20 in. per min. depending upon the motor drive used. When the tape travels at 10 in. per min., 1 in. on the tape represents .1 min. and one-tenth of an inch equals .01 min.

Under the latest methods, analysis is made by measuring the time values on the tape with a steel scale graduated to 1/50 in., which comes

with the instrument. Readings to 1/500 min. are thus possible when the tape travels at the rate of 10 in. per min. Fig. 7 shows a section of tape upon which time intervals have been recorded.

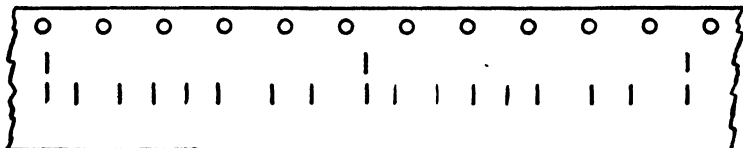



FIG. 7. Marstochron Tape

WINK-COUNTER.—This device, originated by David B. Porter, is used for both motion and time studies. In appearance it resembles a "speedometer." The wink-counter has three revolving numbered discs from which the time can be read accurately to .005 min. for time studies, while for motion studies a helix on the machine may be used for closer timing. The device is positioned at the workplace, and the observer reads the counter at practically the same instant he observes the motion of the operator. Greater accuracy is obtained than with the stop-watch and shorter elements can be recorded.

STOP-WATCH, WINK-COUNTER, AND MARSTOCHRON COMPARED.—Studies of the decimal-minute stop-watch, the wink-counter, and the Marstochron were made by Porter and similar studies by Leng. From these experiments considering the improved Marstochron, it may be said that 2 to 5 times as many observations are necessary with the stop-watch as with the wink-counter, and from 10 to 30 times as many with the stop-watch as with the Marstochron, for equal confidence in results.

With the Marstochron, an element of .01 min. can be read as readily as .10 min. using the stop-watch; for the wink-counter, the smallest element recommended is .025 min., an element which is getting below the range of the stop-watch method.

MECHANICAL TIME RECORDER.—A mechanical time recorder may be used to record productive time lost (Fact. Mgt. & Maint., vol. 98). The recording device consists of a graduated chart (Fig. 8) revolving once in 8 or 10 hr. upon which a jagged line is made by vibration when the machine being timed is running, and when the machine stops a single line is recorded. Delay causes are noted by the operator or other person.

TIME OBSERVATION SHEETS.—There is considerable variation in time observation sheets, depending upon the technique used by the analyst in taking observations. The essential feature of a well-designed observation sheet is that it provide space for all necessary data. Both sides should be used, one side for time study observations and the other for all additional data of identification, analysis tools, etc.

INTERRUPTION SHEETS.—These are used in studies involving automatic and semi-automatic machines. The object is to obtain infor-

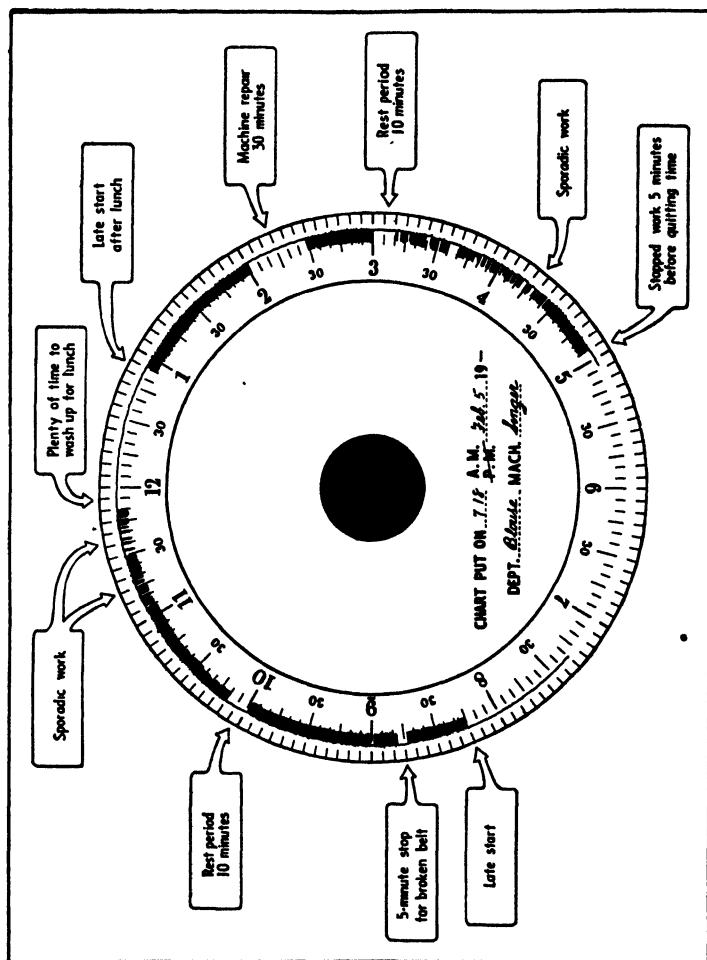



FIG. 8. Chart of a Full Day's Work on a Sewing Machine

mation as to frequency and elapsed time of all delays to operation. They are generally used to obtain data over at least a full day's period. Fig. 9 is an example of such a sheet. This form is useful in obtaining data on two or more machines in a group, in which case a separate sheet is used for each machine. The watch is allowed to run continuously throughout the observation period and readings are entered on sheets as various events occur. Subtractions in the column headed "elapsed" are made after the observation period is over and the results may then be sum-

OPERATION ________ TEST #3 SHEET #1

OPERATOR ________ MACH. NO. 71 (LOOM)

OBSERVER C. N. U. DATE 11/13/-

TIME			REMARKS
FROM	TO	ELAPSED	
0	3.82	3.82	Late start
3.82	5.40	1.58	Oil machine
5.40	6.20	.80	Interference
6.20	7.43	1.23	Broken warp
7.43	7.53	.10	Weave
7.53	9.73	2.20	Interference
9.73	10.90	1.17	Broken filling
10.90	11.07	.17	Interference
11.07	12.20	1.13	Broken filling
12.20	12.30	.10	Interference
12.30	13.18	.88	Broken filling
13.18	13.30	.12	Interference
13.30	13.58	.28	Broken filling
13.58	17.00	3.42	Weave
17.00	17.55	.55	Broken filling
17.55	17.65	.10	Interference
17.65	19.35	1.70	Change shuttle
19.35	19.40	.05	Weave
19.40	20.80	1.40	Broken filling
20.80	22.27	1.47	Weave
22.27	23.04	.77	Interference
23.04	23.15	.11	Broken filling
23.15	27.95	4.80	Left machine
27.95	28.63	.68	Broken filling
28.63	28.78	.15	Interference
28.78	29.20	.42	Broken filling
29.20	32.33	3.13	Weave
2.33	2.43	.10	Change shuttle
2.43	4.20	1.77	Weave
4.20	4.42	.22	Interference
4.42	4.48	.06	Loom slipped off
4.48	5.60	1.12	Weave
5.60	5.65	.05	Change shuttle
5.65	8.17	2.52	Weave
8.17	8.24	.07	Change shuttle
8.24	10.47	2.23	Weave
10.47	10.56	.09	Change shuttle
10.56	11.95	1.39	Weave
11.95	12.00	.05	Change shuttle
12.00	13.97	1.97	Weave
13.97	14.03	.06	Change shuttle
14.03	16.20	2.17	Weave

FIG. 9. Method of Recording Data on Interruption Sheet

MILL	DEPT.	OPERATION	SIZES	DEPT	OPER.
SPUN SILK	FINISHING	Reeling on 44″ Drum — Skeins Tied on 2 Sides Previously Controlled	20—24 or 1050—1260	PDF	

MR. H. Blank, Supt. Date 3-30

We Recommend the Following Task on the Above Work

SIGNED

RATE SYMBOL	HOURS PER —REV. —LB.	Doff Per Reel .33	PER CENT BONUS 20	MAX. RATE WORKMAN	MACHINE SYMBOL	Reels Atwood Auto-Stop

ANALYSIS: Studies have been made to determine the number of doffs an operator should take off one reel for sizes 1050 through 1260 which have been controlled first and which take 2 lebands per skein. The task is based on an average drum speed of 215 RPM, and an average of 2750 yards of silk per skein with a maximum weight of 2.62 oz. For a description of the operation see the "Discussion of Tasks for Reeling from Large Gasser Spools on Atwood Auto-Stop Reels." Dec. 29, 19—.

DETAIL OPERATION:		Time Necessary
A	Cut end and tie around skein with other end	.06 Min.
B	Put end waste and scissors into pocket, turn reel ¼ turn	.05
C	Lease or band one side of one skein	.05
D	Turn reel through a ½ turn	.02
E	Knock down reel drum and strip off the 15 skeins	.19
F	Walk to pile, place doff on pile, and return to reel	.06
G	Connect 15 ends to the drum	.24
H	Set automatic knock-off gear and start reel	.08
J	Straighten out two skeins on drum. Does not occur on this task...	...
K	Tie up one broken end (average)	.37
L	Replace one empty spool with one full spool (average)	.34
M	Walk to the reel (average)	.07
N	Machine running time at 2.50 turns of the knock-off gear	10.47 Min.

SYNTHESIS: In reeling one doff there are the following hand operations: Cut and tie the ends for 15 skeins; put end waste and scissors into pocket and turn reel through a ¼ turn; band 15 skeins on one side; turn reel through a ½ turn; band the opposite side of the 15 skeins; knock down drum and strip off the 15 skeins; walk to pile and return to reel; connect 15 ends to the drum; set knock-off gear and start reel. The supplementary hand operations are as follows: the average number of broken ends to tie up is 1.35; the average number of empty spools to replace is 3.7, based on 4.06 doffs per set of 15 spools; and the number of times it is necessary to walk to the reel to perform the above hand operations is 2. Therefore there is the following hand time per doff:

(15A + B + 30C + D + E + F + G + H +1.35K + 3.7L + 2.0M)	
(.90 + .05 + 1 50 + .02 + .19 +.06 +.24 + 08 +.50 + 1.258 + .14)	4.94 Min.
Add 20% of (15A + B + 30C + D + E + F + G + H) for rest and delay	.61
Total Hand Time per Doff	5.55
The necessary machine time to run one doff	10.47
Add 5% for variation in speed of the drum	.52
Total Machine Time per Doff	10.99
The total hand time plus the machine time will be 5.55 + 10.99	=16.54
Add 2¾% for personal time	.46
	17.00
Add 15% for interference	2.55
Total Time Allowed per Doff	19.55 Min.

The rate or time allowed per doff per reel $= \frac{19.55}{60} =$ .326 or .33 hr.

A bonus of 20% is recommended.

CHECKED H. E. F.
APPROVED

FIG. 10. Specimen Task Report
(D. B. Porter)

marized for study. (See later discussion in this Section in connection with Fig. 51.)

REPORT FORMS.—These are frequently used for writing up the results of a study. The object of the write-up is to make a permanent record of method details and elementary operation times. Fig. 10 is an example of one such form that can be used for any kind of study. Where there are sufficient studies of one special kind to be made, time can often be saved in the write-up by devising a special single-purpose form.

Taking the Time Study

PRELIMINARY INVESTIGATION.—Before starting on any extensive job standardization work, it is desirable to make a **record of what is being done.** This record is of value in making appraisals of progress. Usually such data exist, and need only to be arranged or charted.

A process chart and study of production process as a whole should always be made at the beginning. Fig. 13 illustrates a flow process chart for the manufacture of a coil spring. Such analysis of a whole series of operations in sequence frequently leads to eliminations and improvements. Special attention should be paid to methods for possible improvement. When the best job sequence and equipment have been determined upon, the best arrangement of machines, work benches, and reserve spaces should be studied. Whether equipment has to be used for different sequences or for one or two only, will affect the arrangement, and in the former case it may be advisable to segregate like machines and in the latter case it may be advisable to depart from all usual modes of arrangement.

In **highly standardized work** the arrangement should follow the sequence of operations and avoid all unnecessary movement regardless of appearances. This study may develop desirable **alterations in buildings and interdepartmental conveying practice.** The system for moving material within a department should be worked out before machines and benches are finally located. Rough estimates based upon best past performance can be used tentatively to ascertain the approximate proportion between the various steps. Such study results in a layout which will not be altered seriously by final job studies. Methods of handling material from one operation to the next may have a great influence on the individual place of work, posture of worker, and all local arrangements. For instance, in sewing-machine operations, if work flows from one operation to the next without going into bundles, tables should be continuous and lengthwise of the room on the window side of the aisle. On the other hand, if work goes into bundles between operations, it may be more convenient to run tables crosswise of the room, thus allowing better light distribution. Finally, machine speeds and other similar factors must be carefully worked out and specified to protect the quality of the product.

The foregoing discussion applies to process charts on short-cycle repetitive jobs. Frequently, long jobs have to be recorded as the study progresses.

TYPE OF WORKER TO SELECT FOR STUDY.—The worker selected for the study depends somewhat upon the procedure used but is a very important factor in the success of the study. Stop-watch procedure has difficulty in recording the finer portions of high dexterity and shows its best results with **steady, normal workers.** Micromotion and compromise techniques can and should make use of the **very best workers.** Both aim to capture the best and this is possible only under conditions of human automaticity.

The **foreman and existing production records will assist the analyst** in selecting the worker to study. In general, intelligence and ability to learn are as important as dexterity and ability to maintain high production. The worker should be one who has the respect and confidence of the workers at large, for he or she interprets the work of the analyst to them and can do much to help or hinder its acceptance.

The analyst should make **selection of the worker part of the preliminary investigation.** During the preliminary investigation he can learn who the best workmen are and which ones are most likely to cooperate, lead, etc. Sometimes, however, he has only a limited choice or none at all.

CHIEF OBJECTIVE.—The chief objective of any job study should be finding or developing "the one best way" of performing the job with the means at command, and recording it so that it may be used to teach others. Finding "the one best way" may be done by finding the champion worker and studying his methods and motions, or by finding separate sets of motions from different subjects and bringing them together to make the complete new method. When the best possible elements do not exist, they can often be developed. In short, the main purpose is improved operation, that is, better economy of effort and other factors involved. Management undertakes to help the worker rather than to drive him.

ATTITUDE OF ANALYST TOWARD WORKER.—The analyst should work in the fullest cooperation with both foreman and worker. The foreman should introduce the analyst to the operator and the latter should be guaranteed no loss of earnings during the study. The analyst should treat the worker as one sharing in the investigation and should endeavor to win his interest and cooperation. Generally there is little difficulty with intelligent workers who want to avoid delays caused by poor material, irregular serving, bad work on preceding operations, or improper care of equipment, which hold down their earnings and cause irritation. The stop-watch should be shown to the operator, its use explained, and the idea of measuring explained as against the idea of driving. The **operator should be put at ease** and instructed to work at the normal rate. The time study man should avoid standing in front of or directly behind the operator and select a position from 4 to 6 ft. away at one side. It is reassuring to the operator if he can look around at the analyst occasionally and the analyst may need to ask questions now and then.

PREPARATION FOR TAKING JOB DATA.—The analyst should so arrange and simplify his own routine that he can give his whole attention to the job being studied. He can make himself comfortable but should not lounge or relax his attention. He must keep off

outside interference and try to put himself into the worker's situation. He must be on the alert to catch all the variables. They divide into those having to do with the worker, the surroundings, and motion. Motions may be classified as frequent and infrequent. The latter are the ones most likely to be overlooked—for instance, starting new stock, oiling machines, changing tools. In many industries there are variables due to season, changes from light to heavy materials, etc. No variable likely to affect motion and time should be ignored.

Taylor (Shop Management) says:

> In making time observations absolutely nothing should be left to the memory of the analyst. Every item, even those which appear self-evident, should be accurately recorded. The writer and his assistant who immediately followed him, both made the mistake of not putting the results of much of their time study into use soon enough so that many time observations which extended over a period of months were thrown away in most instances because of failure to note some apparently unimportant detail.

Blanks should be prepared and all **general data covering conditions** filled in such as date, time of starting and stopping, operation, work in process, operator, machine or workplace, temperature, humidity, light, sound, etc. Figs. 11 and 12 show complete blanks for an extensive study of machine operations where considerable supporting data must be recorded. In a particular plant the form can be simplified to contain only the information essential to that work. The commonest size of form is 8½ x 11 in.

RECORDING TIMES.—When elementary operations are in a fixed order, it is better to write them down on each blank before beginning the study of time. If the order cannot be fixed, the operations may be listed at the bottom of the sheet and given symbols, a, b, c, etc. These symbols can then be used in any sequence which may develop. There is some danger of miscopying, but it is not always possible to fix the sequence completely. Clearness as to just what constitutes an elementary operation is important. In such divisions as adjust tool in post, tighten tool, position, there is danger of being indefinite as to exactly where one ends and the next begins. **Transition** points should be definitely given as:

1. From reaching for tool
   To end of tool adjustment in post. The method should be described on the back of the sheet or on simple motion study.
2. From end of adjustment in post
   To end of tightening. The method should be described as above.
3. From end of tightening
   To starting machine. The motions of tightening should be described as above.

These transition points must be fixed in mind, and it is safer to write them in advance of time taking. Bassett named elementary operations in one column and noted a **stopping point** after each name in a second column. In establishing these various points use of judgment to cut out unnecessary detail will avoid too much writing. Minutes need not be repeated with every decimal reading but they should be put down frequently enough to prevent doubt.

OVER-ALL TIMING.—Mass timing of large groups of elementary operations is almost useless. It will not permit any scientific analysis, as it neither uncovers delays nor leads to improvement in method, the two main reasons for job study. It is justifiable only as a check. In fact, it is better to break operation down farther than necessary, than not far enough. Divisions can always be combined but they cannot be subdivided without repeating the study.

SNAP-BACK TIMING.—At the beginning of each element the watch hand starts from zero. At the end of each element the watch is read, the hands are snapped back to zero, and the observed time is recorded (see Fig. 11). No computations are necessary to obtain element times, as these are recorded. Thus the clerical work in computing the study is less than in the continuous method. The time taken by the operator to reverse his finger movement introduces some inaccuracy (the sum of the readings was 2% less than the sum of the over-all times in some studies made by the Pittsburgh Plate Glass Co.).

CONTINUOUS TIMING.—This procedure gives the most satisfactory results in general and on most operations. Elementary operations are recorded in sequence without stopping the watch. The observer keeps the watch going continuously during the period of study, making a mental note of the time as shown on the watch at the instant each elementary operation is completed and recording that time on the sheet opposite its name or appropriate symbol. He should do all this with sufficient speed and concentration to be free to note and write the time of completion of the next elementary operation. As reading of the watch is practically instantaneous, there is no necessity for stopping the hand. The continuous method gives not only the exact time for each elementary operation as a distinct entity, but also the times of all elementary operations in the order of their performance. Further advantages of continuous timing are that it charges every minute of time for the duration of the study either to some necessary elementary operation, called a "productive" elementary operation, or to an unnecessary one, called a "nonproductive" elementary operation; it also eliminates any danger of omitting delays. (Lichtner, Time Study and Job Analysis.) The split-hand watch greatly facilitates the use of this procedure. **Cumulative readings** only are recorded during the run. Elapsed times are derived by subtraction later and entered near the corresponding cumulative readings (Fig. 12). As a check, **the sum of individual times** should equal the final cumulative reading. The latter should not be entered too far from the original readings. A simple way is to enter the cumulative reading with hard pencil on one-half of each square and the extensions with softer or colored pencil on the other half. This method keeps the two sets of figures together and yet allows either set to be scanned without confusion.

CONNECTED TWO-WATCH TIMING.—The connected two-watch procedure allows for direct reading of elapsed time of elementary operations. Two watches are arranged side by side on the study board. A mechanism of connecting links is so arranged that when the first watch is started, the second is automatically stopped. When the second is again started, the first one is stopped. (To use this device, the stop-start arrangement on one of the watches must be reversed, which can be

TIME OBSERVATION SHEET

FACT. NO 18 | DEPT NO 22 | PART NAME Bearing Cap | OPERATION NO. 20A | OPERATION Drill 2 (17/32) Holes | MACH NO 681 | MACHINE 24" Conv. Dr. Press | DATE 5-21- | MODEL NO Std.

PART NO 62B67 | SCHEDULE NO T4920 | CANCELS SCH NO T1151 | GROUP NO none | PAGE 2 OF 3

		NO.	DETAILS OF WORK CYCLE	ELAPSED TIME IN DECIMAL MINUTES										ALLOWED TIME		
SKETCH (OVER)	✓														IDLE TIME/CYCLE	60
REMARKS (OVER)	✓	1	Place 1 part in fixture (27")	03	.04	.04A	04	.05	.03	.07	.03	.04	.05	04	IDLE TIME/PIECE	60
SAFETY	OK	2	Clamp 1 part (socket wrench & nut)	.08	.07	.09	.09	.08	.10	.09	.10	.08	.07	06	DELAY/PIECE	✓
LUBRICANT	Sol. Oil	3	Lower drill head (3")	03	03	.03	.02	.03	.04	.03	.04	.02	.03	02	MACH CAP'TY/HR	57
DRIVE	Elect.	4	Drill 2 holes (17/32 x 2)	68	.66	65	.69	.67	.66B	.68	.67	65	.65	65	OPER CAP'TY/HR	57
LOT SIZE	✓	5	Mach. feed trip, raise head	02	.04	03	.02	.02	.02	.03	.04	.02	.03	02	PIECES/CYCLE	1
LOTS/YEAR	✓	6	Release 1 pt (socket wrench & nut)	05	.05	.06	.07	.08	.05	.06	.07	.06	.08	05	RE'QD PROD/HR	50
CONT US PROD	Yes	7	Remove 1 part (16")	03	03	.04	.05	.04	.03	.03	.05	.04	.05	03	NO PCS STUDIED	10
CONE STEP US D	✓	8	Blow out fixture (Hose)	05	05	.06	.05	.05	.05	.04	.05	.06	.04	05	NO OF OPERATORS	1
FEED LEVER	010	9													NO OF HELPERS	✓
SPEED LEVER	✓	10													NO OF MACHINES	1
MATERIAL		11													FORMER BASE RATE	65¢
Mall. Iron		12													NEW BASE RATE	65¢
DELAYS		13													FORMER STD TIME	0160
		X	4A - go to next spindle to spotface	see oper. #20B											NEW STD TIME	0175
A (12) 08 Examine fixture		X	4B - spotface 2 holes												FORMER PROD/HR	62.5
		X	4C - return to position												NEW PROD/HR.	57
B Change drill 74		17													% INCREASE PROD	✓
		18													% DECREASE PROD	10
C		19													% INCREASE TIME	9.4
		20													% DECREASE TIME	✓
D		21													FORMER COST/PC	0109
		22													NEW COST/PC	0119

ITEM #	4	WORK CYCLE TIME PER PIECE	920	
CUTTING DIA	.693	MULTIPLE PCS/WORK CYCLE, PCS, PRORATE/PC	✓	DEMONSTRATION
CUTTER DIA	"	" MACH./ " " , MACH, " /MACH	✓	GOOD ☑ FAIR ☐ POOR ☐
NO OF TEETH	2	" OPERS/ " " , OPER, " /OPER	✓	APPROVED BY
CUTTER MATL	HSS	HANDLE SUPPLIES MIN FOR /PCS, " / "	✓	
R P M WORK/TOOL	360	" SCRAP " " / " ; " / "	✓	ANALYST
F P M WORK/TOOL	56	" STOCK TO WORK AREA 30 " " 15 / " , " / "	020	
TYPE OF CUT	Dr.	" " FROM " " 36 " " 15 / " , " / "	024	CHECKER
FEED/REV. WORK/TOOL	010	MACH SET UP TIME ALLOWANCE ✓ %, MIN/SET UP, " , " / "	✓	
FEED/MIN. WORK/TOOL	36	TOOL CHANGE TIME ALLOWANCE " , 1 MIN/CHANGE 200 " , " / "	.005	FOREMAN
FEED/TOOTH WORK/TOOL	005	REST OR DELAY ALLOWANCE ✓ " , MIN/DAY, " , " / "	✓	
LENGTH OF CUT	2¼	MACHINE ALLOWANCE ✓ " ; 19 " / " , " , " / "	✓	GEN FOREMAN
WIDTH OF CUT	✓	SPECIAL ALLOWANCE ✓ " , " / " , " , " / "	✓	
DEPTH OF CUT	2"	PERSONAL ALLOWANCE ✓ " , 21 " / " , " , " / "	✓	
LIMITS	✓	TOTAL ALLOWANCE 9 " , 40 " / " ; " , " / "	083	
REASON FOR CHANGE Holes were 17/32 dia		TOTAL TIME ALLOWED PER PIECE	1.052	SUPERINTENDENT

FIG. 11. Method of Recording Snap-Back Time Study

TIME OBSERVATION SHEET

FACT NO. 18 — DEPT. NO. 22 — DATE 5-21- — MODEL NO Std. — PART NO 62B67
PART NAME Bearing Cap — SCHEDULE NO T4920
OPERATION NO. 20B — OPERATION Spotface (2) 1 3/16 Holes — CANCELS SCH NO T1151
MACH. NO. 682 — MACHINE 24" Com Dr. Press — GROUP NO none — PAGE 3 OF 3

		NO.	DETAILS OF WORK CYCLE	ELAPSED TIME IN DECIMAL MINUTES										ALLOWED TIME		
SKETCH (OVER)	✓			CONT	INDV	CONT	INDV	CONT	INDV	CONT	INDV	CONT			IDLE TIME/CYCLE	none
REMARKS (OVER)	✓	1													IDLE TIME/PIECE	none
SAFETY	OK	2													DELAY/PIECE	none
LUBRICANT	Sol Oil	3	Place part under spotfaces (18")	02	02	.60	.03	.94	.02	1.57	.02	1.94	.04	.02	MACH CAP'TY/HR	162
DRIVE	Elect	4	Lower spindle (4")	.04	02	.63	.03	.96	.02	1.59	.02	1.96	.02	.02	OPER CAP'TY/HR	162
LOT SIZE	✓	5	Spotface (1 3/16 x 1/16)	.20	16	.74	.11	1.06	.10	1.72	.13	2.07	.11	.11	PIECES/CYCLE	1
LOTS/YEAR	✓	6	Raise spl., turn part end for	23	03	.77	.03	1.10	.04	1.75	.03	2.10	.03	.03	RE QD PROD/HR	50
CONT US PROD.	Yes	7	end & lower spl.												NO PCS STUDIED	5
CONE STEP US D	✓	8	Spotface (1 3/16 x 1/16)	.42	.19	.87	.10	1.50B	.11	1.85	.10	2.22	.12	.11	NO OF OPERATORS	1
FEED LEVER	✓	9	Raise spindle	.44	.02	.90	.03	1.52	.02	1.87	.02	2.24	.02	.02	NO OF HELPERS	✓
SPEED LEVER	✓	10	Remove part (22")	.57A	.03	.92	.02	1.55	.03	1.90	.03	2.26	.04	.03	NO OF MACHINES	1
MATERIAL		11													FORMER BASE RATE	65¢
Mall Iron		12													NEW BASE RATE	65¢
DELAYS		13													FORMER STD TIME	0059
		14													NEW STD TIME	0062
A Drop & pick up (13)		15													FORMER PROD/HR	175
		16													NEW PROD/HR	162
B Move stock	40	17													% INCREASE PROD	✓
		18													% DECREASE PROD	8
C		19													% INCREASE TIME	5
		20													% DECREASE TIME	✓
D		21													FORMER COST/PC	0037
		22													NEW COST/PC	0040

ITEM #	5-8	WORK CYCLE TIME PER PIECE	34	
CUTTING DIA.	1 3/16	MULTIPLE PCS/WORK CYCLE, PCS, PRORATE/PC	✓	DEMONSTRATION
CUTTER DIA.	"	" MACH/ " ", MACH, " /MACH	✓	GOOD ☑ FAIR ☐ POOR ☐
NO OF TEETH	4	" OPERS/ " ", OPER, " /OPER	✓	APPROVED BY
CUTTER MATL.	HSS	HANDLE SUPPLIES , MIN FOR /PCS, " / "	✓	
R P M. WORK/TOOL	220	" SCRAP " " / " ; " / "	✓	ANALYST
F. P. M. WORK/TOOL	69	" STOCK TO WORK AREA " " / " ; " / "	✓	
TYPE OF CUT	SF	" " FROM " " / ", " / "	✓	CHECKER
FEED/REV. WORK/TOOL	HD	MACH SET UP TIME ALLOWANCE ✓ %, MIN/SET UP ", " / "	✓	
FEED/MIN WORK/TOOL	"	TOOL CHANGE TIME ALLOWANCE ", 3 MIN/CHANGE, 400 ", " / "	007	FOREMAN
FEED/TOOTH WORK/TOOL	"	REST OR DELAY ALLOWANCE ✓ ", MIN/DAY, ", " / "	✓	
LENGTH OF CUT	1/16	MACHINE ALLOWANCE ✓ ": 10 " / ", ", " / "	✓	GEN FOREMAN
WIDTH OF CUT	✓	SPECIAL ALLOWANCE ✓ ", " / ", ", " / "	✓	
DEPTH OF CUT	1/16	PERSONAL ALLOWANCE ✓ ", 21 " / ", ", " / "	✓	
LIMITS	1/64	TOTAL ALLOWANCE 7 ": 31 " / ", ", " / "	024	
REASON FOR CHANGE Was 1" dia.		TOTAL TIME ALLOWED PER PIECE	371	SUPERINTENDENT

FIG. 12. Method of Recording Continuous Study

done by any watch repair man by reversing the hair spring which controls the mechanism in the watch.) The analyst reads the watches alternately and gets direct readings for elapsed times. This method saves the necessity of subtracting successive readings to get elapsed times, thereby avoiding much clerical work.

LENGTH OF STUDY.—It is the usual practice when the cycle time is less than a minute to take a time study of 15 to 20 min. length. When cycles are short, many observations are obtained in a short time and the study need not be so long. Studies, however, may range from a few minutes' check to those extending over several days.

When there are variations caused by the operator, work, or conditions, more cycles should be observed. Two short studies, taken at different times, are better than one long study.

Analysis of Operations

BASIS OF OPERATION ANALYSIS.—Operation analysis consists of a detailed study and analysis of each operation to determine whether the operation is necessary, and the best and quickest method of performing that operation with the best available tools, equipment, materials, and working conditions. It may be applied to simple or complex operations, repetitive or nonrepetitive work.

The analysis can be made by supervisors, foremen, or methods men who are experienced in the requirements of the particular class of work and who understand the principles involved.

The extent and type of study economically justified on any class of work are determined by the number of times the operation is repeated per year, the length of the operation, the labor content (that is, a fully manual operation as compared with one on an automatic machine), and the anticipated life of the job.

ESSENTIALS OF OPERATION ANALYSIS.—The essentials of operation analysis can be given under ten headings as follows:

1. Operations performed (flow process charts).
2. Job performed (analysis sheet, process chart).
3. Inspection requirements.
4. Material specifications.
5. Materials and work in process handling.
6. Machine and auxiliary equipment.
7. Tools, jigs, and fixtures.
8. Preparation and set-up.
9. Working conditions.
10. Workplace and plant layout.

EXAMPLES OF ANALYSIS.—Several examples of operation analysis in silverware manufacturing are given by Morrow. The principles of operation analysis and method change were applied to the operation of annealing nickel-silver blanks and subsequent pickling, dipping, and drying. Changes in method were made, equipment was rearranged, large metal baskets were substituted for small earthenware crocks formerly used in dipping, and a drying operation was entirely eliminated. The drying operation was formerly done by moving the

metal blanks back and forth on a wire screen, through which hot air was blown. By merely raising the temperature of the last dip to 210°F. and leaving the blanks in this dip longer, they dried of their own heat. A cost reduction of over $1,000 per year was effected, with a 28% increase in operator's earnings. The savings and increased operator earnings were obtained in part by methods improvements and in part by a gang wage payment plan.

An operation studied was cold rolling of nickel-silver blanks. Most of the articles put through the rolls required two passes, but this article required only one pass. The handling time was therefore less, and it was possible to speed up the rolls so that the handling and machine times would balance. It was not desired to change the premium rate, and the operator's earnings were therefore increased approximately 12% with no cost reduction.

In a knife-cleaning operation the knives were formerly washed on a wheel, racked, cleaned, and dried in sawdust. All these operations were eliminated, the articles were simply wiped with cloths, and better results were obtained. Cost reduction was $3,300 per year. Operators were paid at the same hourly rate before and after the change of method was effected.

The procedure followed in a large plating department, where operations throughout the department were studied, was:

1. Time and motion studies were made of existing methods.
2. Methods were standardized.
3. Minor rearrangement was made of equipment.
4. A group incentive plan of wage payment was installed.

The result obtained for all operations in the department was a total cost reduction of $24,000 per year, with operator earnings increased approximately 20%.

Two factories were manufacturing similar meat dishes made of nickel-silver, polished, buffed, and plated. The article was sold in a highly competitive market. Operations in the two factories were compared. It was found that one meat dish was carefully polished on the under side, while the other was not. No good reason was found for this polishing operation and it was entirely eliminated, resulting in a much-needed manufacturing cost reduction.

Flow Process Charts.—In making an over-all study of the operations performed in the manufacture of a part, the flow process chart is especially useful. The chart will aid in analysis of operations, sequence, inspections, storage, and distances moved. Such analysis of a whole series of operations in sequence frequently leads to elimination of, and improvements in, operations. When the best job sequence and equipment have been decided upon, the best arrangement of machines and work benches should be studied. Whether equipment has to be used for many parts requiring different sequences or whether the equipment can be used exclusively for one part and one sequence of operations will determine the machine arrangement.

How to analyze present operations, decide which are necessary, work out the best sequence, and make a new plant layout if necessary, is described by Mogensen (Fact. Mgt. & Maint., vols. 92 and 93).

Flow charts are constructed for each of the major products by following either material or men throughout the entire process.

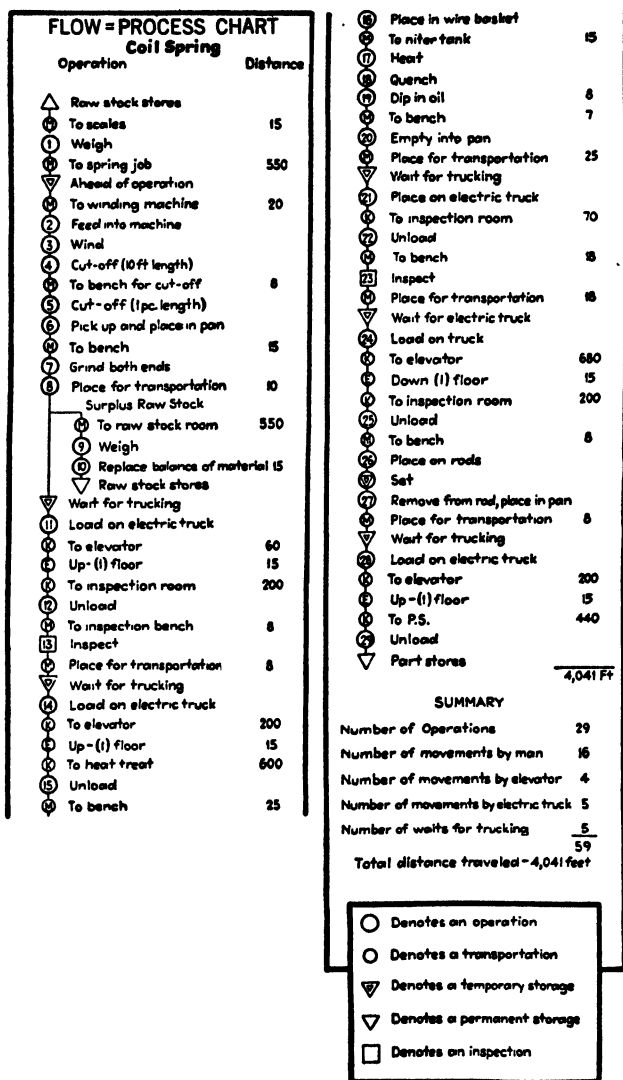



FIG. 13. Flow Process Chart for Coil Spring—Old Method

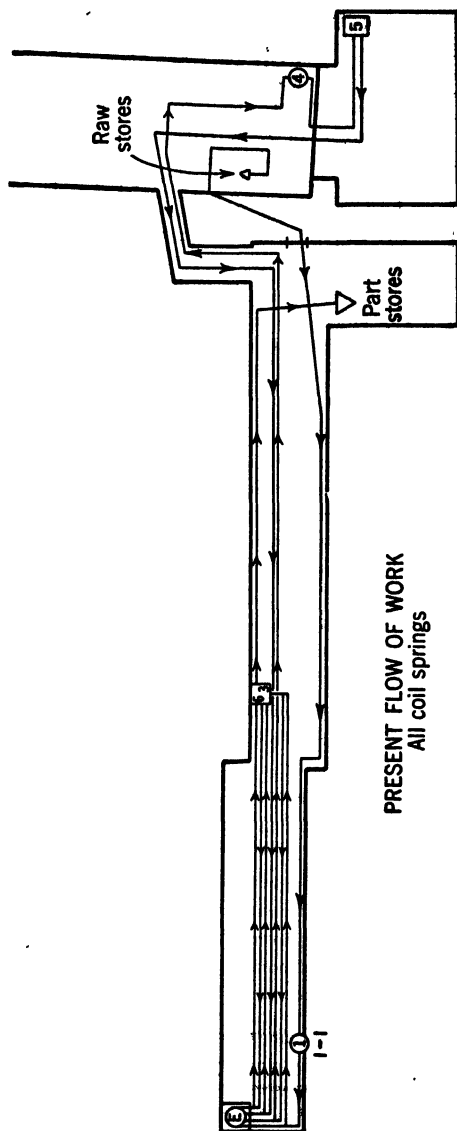



Fig. 14. Layout Showing Flow of Work on Coil Spring—Old Method

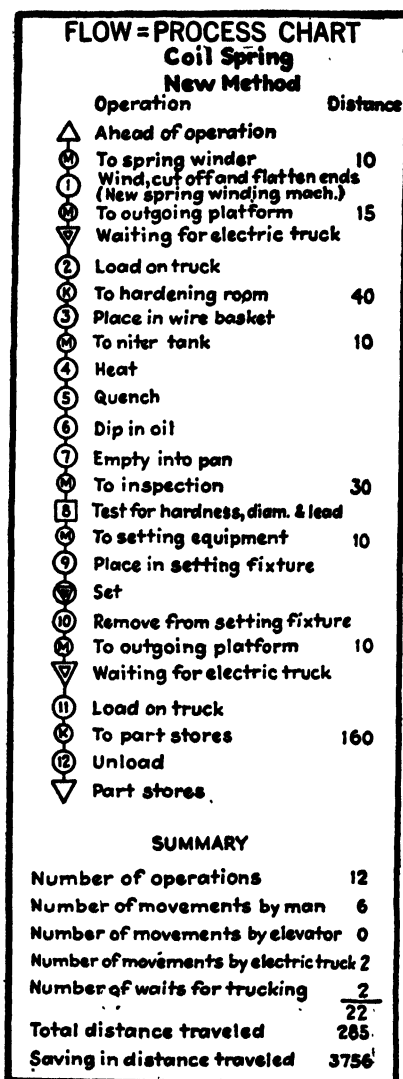



Fig. 15. Flow Process Chart for Coil Spring—New Method

The flow chart (Fig. 13) and layout (Fig. 14) were made for a typical small spring. The flow chart showed 59 steps in the manufacture of the spring, which traveled 4,041 ft. (A standardization committee set up under the auspices of the American Society of Mechanical Engineers has recently proposed slight modification of the symbols used when the charts were drawn as shown here.)

Every operation indicated on the chart was analyzed and four tests applied:

1. Can the operation be eliminated?
2. Can it be combined with some other operation?
3. Can it be simplified?
4. Can a better sequence of operations be used?

An improved flow chart and layout were made, after operations were eliminated, combined, and their sequence changed or simplified, as shown in Figs. 15 and 16. This change reduced distance traveled to only 285 ft., a saving of 3,756 ft. over the previous method. Operations were reduced from 59 to 22.

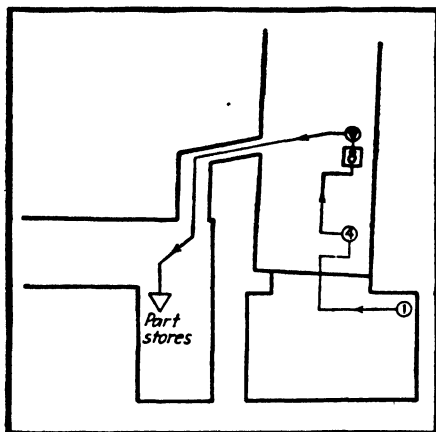



Fig. 16. Layout of the Flow of Work on Coil Spring—New Method

ANALYSIS SHEET OF JOB PERFORMED.—The analysis sheet aids in clear analysis with a record of conditions at the time of analysis and of improvements suggested and made. The use of an analysis sheet on a simple milling machine operation is illustrated in Figs. 17 and 18 (Maynard and Stegemerten, Operation Analysis).

ANALYSIS OF JOB PERFORMED.—Approach to operation analysis is made by a thorough study of the operation and application of the principles of motion and time economy.

Date *Oct. 16, 19--* Dept. *Small Machining* Dwg. *822304* Sub. *2*

Mould ____ Die ____ Style ____ Item *4*

Pattern *8191-A* Ins. Spec. ____ L. Spec. ____ Sub. ____

Part Description *Clamp for Type XX Regulator Shaft*

Operation *Mill Slot* Operator *Jones*

DETERMINE AND DESCRIBE	DETAILS OF ANALYSIS
1. PURPOSE OF OPERATION *To mill slot in casting. Slot fits Regulator Shaft - Dwg. 122301*	Can purpose be accomplished better otherwise?
2. COMPLETE LIST OF ALL OPERATIONS PERFORMED ON PART No. — Description — Work Sta. — Dept. 1. *Make Casting* — — *Foundry* 2. *Mill Slot* — *Small Milling Machines* — *Small Machining* 3. *Drill two Holes* — *Sensitive Drill Press* — *Small Machining* 4. 5. 6. 7. 8. 9. 10.	Can oprn. being analyzed be eliminated? be combined with another? be performed during idle period of another? Is sequence of oprns. best possible? Should oprn. be done in another dept. to save cost or handling?
3. INSPECTION REQUIREMENTS a - Of previous oprn. *Casting must be filled out completely and have no porous spots, rough spots, or burned in sand.* b - Of this oprn. *± .002". This tolerance unnecessarily close for purpose. Checked with Schauer advisability of changing to ± .005". Will advise 10/14/- OK changed 10/19* c - Of next oprn. *Holes must be properly located and to drawing dimensions.*	Are tolerance, allowance, finish and other requirements necessary? too costly? suitable to purpose?
4. MATERIAL *Common Brass. OK. Brass must be used to avoid rusting. Alloy specified is inexpensive and easily machined.* Cutting compounds and other supply materials *None*	Consider size, suitability, straightness, and condition. Can cheaper material be substituted?
5. MATERIAL HANDLING a - Brought by *Conveyor* b - Removed by *Conveyor* c - Handled at work station by *Operator by hand*	Should crane, gravity conveyors, totepans, or special trucks be used. Consider layout with respect to distance moved.
6. SET-UP (Accompany description with sketches if necessary) *Standard vise is bolted to machine table with two bolts. Totepan is placed on floor to left of machine. Empty totepan to receive machined parts is placed on floor to right of machine.* a - Tool Equipment Present *Standard vise. 6" spl. side cutter S-807* Suggestions *Use vise with quick acting clamp* — *Adopted 10/20* *Provide ejector for removing part from vise* — *Adopted 10/20*	How are dwgs. and tools secured? Can set-up be improved? Trial pieces. Machine Adjustments. Tools Suitable? Provided? Ratchet Tools Power Tools Spl. Purpose Tools Jigs, Vises Special Clamps Fixtures Multiple Duplicate

FIG. 17. Analysis Sheet of a Milling Machine Operation (*face*)

7. CONSIDER THE FOLLOWING POSSIBILITIES.	RECOMMENDED ACTION
1. Install gravity delivery chutes. *Adopted 10/17. Recommended to Riley 10/16*	*Yes-from vise to totepan*
2. Use drop delivery	*Not necessary*
3. Compare methods if more than one operator is working on same job.	*Only one operator*
4. Provide correct chair for operator. *Adopted 10/20*	*Must stand to operate 2 machines*
5. Improve jigs or fixtures by providing ejectors, quick-acting clamps, etc. *Recommended to Frank 10/16.*	*Yes-See Tool Suggestions*
6. Use foot operated mechanisms.	*Can operate air hose by foot if nec.*
7. Arrange for two handed operation.	*Not practical*
8. Arrange tools and parts within normal working area. *Adopted 10/20*	*Operator instructed*
9. Change layout to eliminate back tracking and to permit coupling of machines. *Recommended to Riley 10/16.*	*Yes*
10. Utilize all improvements developed for other jobs.	*Done*

8. WORKING CONDITIONS	
Satisfactory a - Other Conditions. *Quantities have recently increased to 50,000 per order, thus justifying suggested more elaborate set-up.*	Light Heat Ventilation, Fumes Drinking Fountains Wash Rooms Safety Aspects Design of Part Clerical Work Required (to fill out time cards, etc.) Probability of Delays Probable Mfg. Quantities

9. METHOD OF PROCEDURE (Accompany with sketches or Process Charts if necessary)

a - Before Analysis and Motion Study.

Pick up small part from table
Place in vise
Tighten vise
Start machine
Run table forward 4"
Engage feed
Mill slot
Stop machine
Return table 6"
Release vise
Lay part aside in totepan
Brush vise

Arrangement of Work Area
Placement of
Tools.
Materials.
Supplies.
Working Posture
Does method follow Laws of Motion Economy?
Are lowest classes of movements used?

b - After Analysis and Motion Study

Machine #1	*Machine #2*
Pick up small part from table	
Place in vise	
Tighten vise	*Mill slot*
Start machine	
Run table forward 4"	
Engage feed	
Turn to machine #2	*Turn from machine #1*
	Return table 6"
	Stop machine
	Open vise (part ejected aside)
	Brush vise
Mill slot	*Pick up small part from table*
	Place in vise
	Tighten vise
	Start machine
	Run table forward 4"
	Engage feed
Turn from machine #2	*Turn to machine #1*
Return table 6"	
Stop machine	*Mill slot*
Open vise (part ejected aside)	
Brush vise	

Saving
.0080 x .55 = 250,000
= $1100.00 per year

See Supplementary Report Entitled. *Man and Machine Process Chart for Mill Slot Oprn.*

Date *10/22/*

OBSERVER *O. Kennedy* APPROVED BY *R*

FIG. 18. Analysis Sheet of a Milling Machine Operation (*reverse*)

Ten important points to be considered are given by Johnson (Fact. Mgt. & Maint., vol. 92):

1. Is the operation necessary? Could it be entirely or partially eliminated?
2. If more than one operator is working on the same job, are they all using the same method? Why not analyze all the different methods and make a "one best method" from the data?
3. Is the operator comfortable? Sitting down as much as possible? Does the stool or chair being used have a comfortable back? Is the lighting good but not glaring? Is the temperature of the work station all right? No drafts? Are there arm rests for the operator?
4. Can a fixture be used? Are the position and height of the fixture correct? Is the fixture the best one available? Would a fixture holding more than one piece be better than one holding a single piece? Can the same fixture be used for more than one operation? Always keep in mind that the human hand makes a very poor clamp, vise, or fixture.
5. Are any semi-automatic tools applicable? For example, a power-driven wrench or screwdriver, or a Yankee socket wrench or screwdriver?
6. Is the operator using both hands all the time? If so, are the operations symmetrical? Wherever possible, both hands should be in motion and moving simultaneously in opposite directions. Could two pieces be handled at one time to better advantage than one? Could a foot device be arranged so that an operation now performed by hand could be done by foot?
7. Are the raw materials placed to the best advantage? Are there racks for pans of material and containers for smaller parts? Can the parts be removed from the containers with ease? Are the most frequently used parts placed in the most convenient location? Remember, the shorter the distance moved, the less the time will be.
8. Are the handling equipment and methods sufficient? Would a roller or belt conveyor improve conditions? Could the parts be placed aside by means of a chute? Drop delivery is desirable where possible.
9. Is the design of the apparatus the best from the viewpoint of the workman? Could the design be changed to facilitate machining or assembly without affecting the mechanical or electrical qualities of the apparatus?
10. Is the job on the proper machine? Are the correct feeds and speeds being used? Are the specified tolerances all right for the use to which the part is to be put? Is the material being used the best for the job? Could one operator run two or more machines?

RIGHT- AND LEFT-HAND PROCESS CHARTS.—The work done by one hand in relation to that done by the other hand is shown by means of right- and left-hand process charts, illustrated in Fig. 19 and Fig. 20. The time per piece in this case was reduced from .0105 hr. per piece (Fig. 19) to .0113 hr. for 2 pieces, or .00565 hr. per piece (Fig. 20) (Fact. Mgt. & Maint., vol. 92).

Movements made by each hand are shown for both the old and the new methods of assembling an arc shield. The chart of the old method (Fig. 19) shows clearly when one hand is idle or holding. It is apparent that the motions of the two hands are unbalanced.

Results of the improvements made are illustrated in the chart (Fig. 20) of the new method. The motions are symmetrical and in opposite directions. Both hands are fully occupied on productive work, resulting in an 86% increase in production.

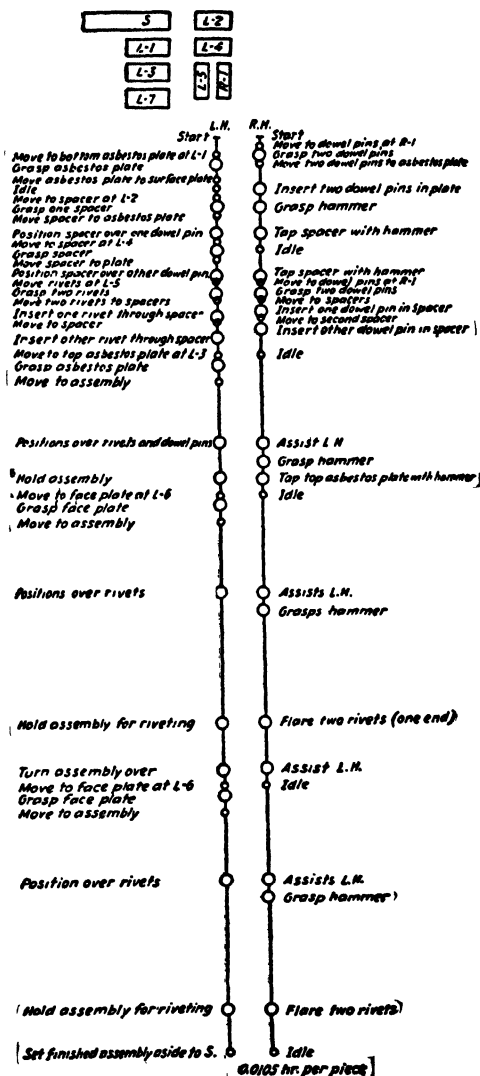



FIG. 19. Process Chart and Layout—Unbalanced Motions Under Old Method

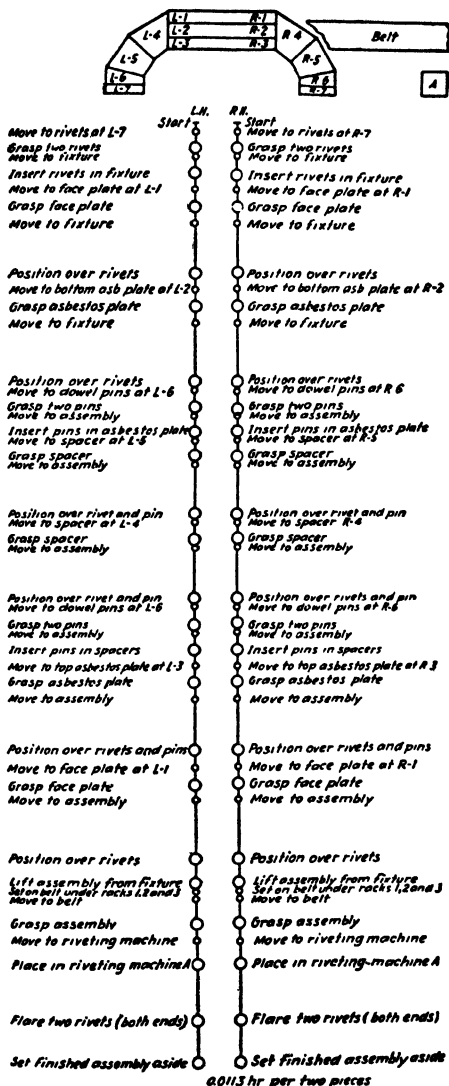



FIG. 20. Process Chart and Layout—Motions Balanced Under New Method

PROCESS QUESTIONNAIRES.—Some form of questionnaire has been found useful to the analyst as a guide to his investigation to insure against overlooking any important factors. The nature of questions will vary in different industries and a list should be carefully prepared for each industry. Some questions are common to all industries. The following lists give some of the most common questions used in questionnaires:

Operation Questionnaire.

1. What is the purpose of the operation?
2. Is the operation necessary? Why?
3. Would some other operation better serve the purpose?
4. Have changed conditions modified its importance?
5. Can it be eliminated by use of different material?
6. Can it be eliminated by improved tools?
7. Can it be eliminated by improved methods?
8. Can the design be changed to eliminate the operation?
9. Can it be partially eliminated?
10. Can it be divided into two or more short operations, or to eliminate hold-up operations in a progressive line?
11. Can it be combined with some other operation?
12. Can the sequence of the operation be changed?

Inspection Requirements Questionnaire.

1. What finish is obtained on the work?
2. Is this grade of finish necessary? Why?
3. Can a cheaper finish be used and be suitable?
4. Can a better finish be obtained at same cost?
5. Is inspection visual or by gages?
6. What are the tolerances?
7. Are these tolerances closer than necessary?
8. Should this work be gaged?
9. How frequently should the work be gaged?
10. How many pieces should be gaged at a time?
11. Are gages of correct type for this work?
12. Are gages in good condition?

Material Specification Questionnaire.

1. Kind and type of material?
2. Grade or quality?
3. Is the material best for the part?
4. Would cheaper material be as good?
5. Should better material be used?
6. Weight of part?
7. Stock defects, such as form, shape, finish.
8. Dimensions of material?
9. Size of material best for least waste?
10. Can scrap or waste be reduced in other ways?
11. Will any such changes affect the economy of previous or subsequent operations?

Materials and Work in Process Handling.

1. What is the nature of materials or parts handled?
2. What are the quantities handled?
3. Is the handling in units or containers?
4. Is the flow continuous or intermittent?
5. Does the material travel set the pace of operations?

6. What operations are performed while materials are moving?
7. What distances do the items travel while under operation?
8. What kinds of handling apparatus are used—cranes, hoists, trucks, conveyors, etc.?
9. Can operations be combined to reduce material handling?
10. Can the operator deliver the part to the next operation when he disposes of it?

Machine and Auxiliary Equipment Questionnaire.

1. Can this work be done more economically by hand or on a machine?
2. If work is done on a machine, what kind is used?
3. Is this the best kind of machine for the purpose?
4. Is machine hand-operated or automatic?
5. Is machine of correct size for the work?
6. Can the present machine be improved for this operation?
7. Is machine in first-class condition?
8. Is machine modern or out of date?
9. If the latter, would it be an advantage, economically, to have a modern machine?
10. Is machine in its proper location with respect to preceding and succeeding operations?
11. Can operator handle one or more machines?
12. Is method of drive satisfactory?
13. What is the drive speed? Is this correct?
14. How often should machine be lubricated?
15. What lubrication is used? Is it the best for the purpose?
16. Is machine properly safeguarded?
17. Are gravity feed containers used to deliver work to the point of operation?
18. Is drop delivery used for the finished article?

Tools, Jigs, and Fixtures Questionnaire.

1. What tools are used?
2. Are these tools correct for the purpose?
3. Has the operator a sufficient number of tools?
4. What cutting speed is used? Feed?
5. What cutting speed should be used? Feed?
6. How frequently are tools ground, using proper feeds and speeds?
7. Are tools properly ground and set? By whom?
8. Can power screwdriver, wrench, or similar tool be used?
9. Is a jig or fixture used? If not, could one be used?
10. Can jig or fixture be improved? How?
11. Is method of locking jig or fixture as quick and convenient as possible?
12. Do all screws and wing nuts turn easily?
13. Is jig or fixture in first-class condition?
14. Are stops used for locating jig or fixture?
15. Should they be used?
16. How many pieces does jig or fixture hold?
17. Can this number be advantageously increased?
18. Is a cutting lubricant or coolant used? Kind?
19. Should a lubricant or coolant be used? Kind?
20. What volume of lubricant or coolant is used?
21. What volume of lubricant or coolant should be used?
22. How are chips, scrap, waste, and dust removed?
23. Would a larger volume of lubricant or coolant remove chips automatically? And how would it affect economy?
24. Is air blast used to remove chips?
25. Could air blast be used?

Preparation and Set-Up Questionnaire.

1. How does operator obtain his work, tools, or supplies?
2. Are there delays at storeroom or toolroom?
3. In what quantities does he get his work?
4. Are these the proper quantities?
5. Could work be delivered to workplace?
6. If work is delivered, is it in most convenient form for operator to use?
7. How is finished work removed?
8. Is this the most economical method?
9. Does delivery method affect subsequent operation?
10. Does operator make his own set-up or are special set-up men provided?

Workplace Layout Questionnaire.

1. Is the workplace laid out to conform to the principles of motion economy?
2. Are tools pre-positioned?
3. Are materials properly located?
4. Is height of bench or machine proper for operator?
5. Should work or operator be raised?
6. Can a chair or stool be used by operator?
7. If used, is chair or stool of proper height with reference to the work?
8. Are lighting conditions good?
9. Are temperature, humidity, and ventilation best for employee and work?
10. Can comfort and convenience of employee be increased? How?

WORKPLACE LAYOUT CHARTS.—Two general concepts underlie workplace layout: (1) classes of motions a human being can make, (2) normal and maximum working areas, which have been described and illustrated by Maynard (Iron Age, vol. 134).

There are five general classes of motions, the lowest being the finger motion: (1) finger; (2) finger and wrist; (3) finger, wrist, and forearm;

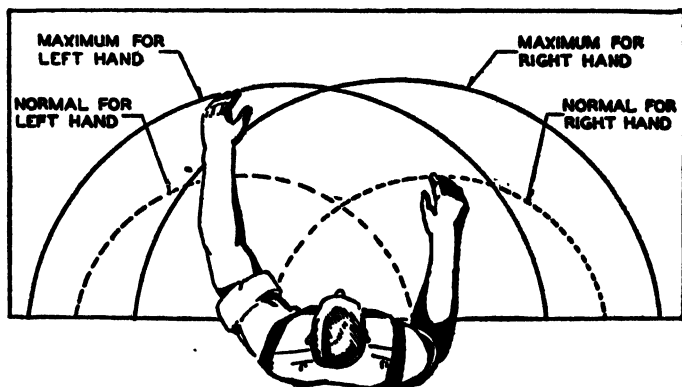



Fig. 21. Normal and Maximum Working Areas for Hands—in Horizontal Plane

(4) finger, wrist, forearm, and upper arm; (5) finger, wrist, forearm, upper arm, and body motions. Motions should be confined to the lowest practical classification. If a job can be accomplished with finger motions only, no further improvement can be made. This statement, of course, must be interpreted with common sense, for, it might be possible to lift a heavy object an inch or so with the fingers, but the same object could be lifted in less time with less fatigue by a combined finger, wrist, and forearm movement.

The second concept is that of normal and maximum working areas. The area in which a worker performs his operation should be kept at a minimum. Fig. 21 illustrates the normal and maximum working areas for the hands in a horizontal plane, as analyzed by J. A. Piacitelli.

PLANT LAYOUT.—Application of time and motion analysis to simplification of plant layout are well illustrated in a straight-line production job on motor-frame machinery at the Westinghouse Electric & Manufacturing Co., described by Johnson (Fact. Mgt. & Maint., vol. 92). In the old layout of Fig. 22, ten operators performed a total of ten

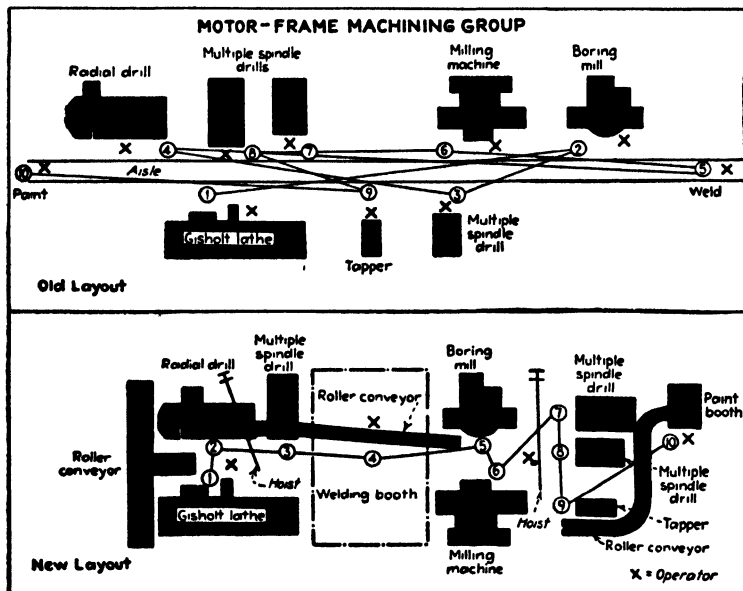



FIG. 22. Old and New Layouts of Motor-Frame Machining Group

operations on each frame. Parts were moved back and forth by the materials handler or machinists themselves. In the new layout (Fig. 22) with the same machines and operations, there is no back-tracking; conveyors and electric hoists have been installed to eliminate manual han-

dling, and operators are able to produce 2½ times as much as they could before.

HABITS AND TRAINING OF WORKERS.—Every analyst has had the experience of teaching operators an improved method and of having them revert to the old method when left alone. They cling to awkward methods because "it has always been done that way." This is perfectly natural. But when centered on improved methods, habit instinct becomes a help and not a hindrance. That is, the cure is building up new habits. For operators, including skilled ones, there must be training of a practical and personal type, followed by supervised practice.

Better methods, although shorter and quicker than old ones, will require a longer time until habit has set up **automaticity of action.** After experience with several well set tasks, the worker gains confidence in standardized times, and he will tackle them without serious hesitancy. For foremen there must be a long and tactful salesmanship. They should never be left out of the calculations. Foremen's meetings with the works manager, analyst, and others should be held frequently and regularly, and informal get-togethers as necessity arises, perhaps several times a day. Management must also be prepared to demonstrate performance of the task, and during training the worker's average earnings should be guaranteed. It is sometimes better to have a separate training department to avoid interference and publicity but the tendency is to do the training right on the job. When training workers at the regular workplace, it must, however, be remembered that the **output of training is progress in learning,** not production of goods. With this fact in mind, quality of method comes first, not quality of goods, which means correct motions from the start without too much regard for spoiled work. Spoiled work may be salvaged by an experienced worker so that the learner will not be confused by repair motions. If correct motions are to be built up, mind and hand must learn to traverse the correct paths, in correct sequence, from the start, and standard speed must be built on this basis by habit. In this way correct motions and automaticity can be crystallized into permanent habit. **Correct motions at automatic speed** mean quality. Slow motions are never quite the same as fast motions, due to muscular tension, momentum, etc. Standard speed is not necessarily maximum speed. It is that speed which will produce the best results. Wrong habits associated with too slow or too fast motions must never be allowed to form during training. Breaking down of old habits is the most difficult part of any training process. Incentives and rest must be provided as in regular production. Some improved methods are so complex that no saving in time is possible at first. With longer training, however, such a task, if on right principles, can always be done in less time.

HUMAN PROBLEMS OF METHOD CHANGE.—One effect of method change is that fewer employees are needed to accomplish the same work. How provision should be made for the displaced employees is suggested by MacNeal (Personnel, vol. 16) in answers to these questions:

1. Can you carry them along until normal labor turnover eases the burden?
2. Can you help them find other desirable jobs, even if you have to help them for a while financially, during the transition period?

3. Can you teach them a new trade in which they can find employment in your own or another plant?
4. Do any of them qualify for pensions?
5. Will a rotational lay-off plan ease the burden all around?

Perhaps none of these methods will fit your problem, but can you ever afford to stop trying to find one that will?

OPERATION IMPROVEMENT REPORT.—Concrete results that may be expected from operation analysis in manufacturing are shown in operation reports. Specimen operation improvement reports (Morrow) are given in Figs. 23 and 24.

MEMO TO ________ Manager DATE: Jan. 15

FROM ________ Industrial Engineer

OPERATION: Upsetting blanks DEPARTMENT: Making

The present method is to stack all blanks at a cost of \$.015 per gross before delivery to the upsetting press. The upsetting cost is \$.040 per gross, total cost \$.055 per gross.

It is recommended that the stacking operation be eliminated. An inclined chute should be constructed for delivering blanks to the press table at a convenient point for the operator to feed press. The unstacked blanks should be dumped into the chute.

The estimated cost of constructing 3 chutes, one for each press, is \$100.

Of the three machines on this operation, 2 are running at 100 r.p.m. and the third at 75 r.p.m. As all machines are of the same type and in good repair, it is suggested that all be run at 100 r.p.m.

Preliminary time studies indicate that the new upsetting price will be \$.045 per gross.

The estimated savings, based on an average production of 2,000 gross per week, are:

Savings = 2,000 × (.055 − .045) × 50	=	\$1,000 per year
Estimated cost of extra equipment	=	100 " "
Estimated net savings for first year	=	\$ 900 " "

The foreman agrees to this change. Your approval is requested.

FIG. 23. Recommendation of Improved Method

MEMO TO ________ Manager DATE: Mar. 11

FROM ________ Industrial Engineer

OPERATION: Upsetting blanks DEPARTMENT: Making

The change in equipment and method, suggested on this operation Jan. 15, ______, has been put into effect, with the following cost reduction:

Savings = 2,000 × (.055 − .045) × 50	=	\$1,000 per year
Cost of extra equipment	=	78 " "
Net savings for first year	=	\$ 922 " "

Operator's hourly earnings have increased 10% under the new method.

FIG. 24. Report on Completion of Change of Method

OVER-ALL COST OF TIME STUDY PROCEDURE.—It is impracticable to establish any figures from experience which are sufficiently representative to serve as a reliable average guide on costs. The fact that time study overlaps with rate work and with product research tends to obscure its cost, not as a matter of confidential information, but as one of unknown figures. Some tendencies or trends can be indicated, but a specific estimate has to be made for the individual case. One measure used is the number of time study men per thousand workers. This depends entirely on the nature of the work. It may range from less than 10 to as high as 20 on strictly jobbing work. The tendency is for the number to rise, owing to (1) the greater emphasis being placed on preliminary methods analysis and (2) the increasing tendency of labor to question standards closely, so that the time study man has tasks of explanation, persuasion, proof, and rechecking. Salaries of individuals follow the general wage scale, and vary considerably with degree of division of labor in the department and capacity for taking responsibility. In making estimates, care should be taken not to base them on understaffing or underpaying in relation to the value of the results it is hoped to obtain.

Fatigue in Factory Operation

FATIGUE REDUCTION.—From the industrial point of view fatigue is defined as:

> That effect of work upon an individual's mind and body which tends to lower his rate or grade of quality of production, or both, from his optimum performance.

Fatigue is only one of numerous forces which may lower productive capacity. Anderson spent a year in research on fatigue under manufacturing conditions. In his study, outlined in the following paragraphs, he states: "Progressive, modern manufacturing methods and management are rapidly eliminating real fatigue from industry. At the present time satisfactory outputs at low cost may be had without unduly tiring workers, and in the future the fatigue factor in industrial work can be, and probably will be, of little importance." In certain work, however, it is still an important consideration and should be understood both as to what it is and how it can be lessened.

LABORATORY EXPERIMENTS ON FATIGUE.—As a physiological phenomenon, fatigue has been studied by physicians, and as a psychological phenomenon, by psychologists. The former studies were usually measurements of oxygen inhaled and CO_2 exhaled by a man riding a bicycle fixed to known loads. Vernon (Industrial Fatigue and Efficiency) summarizes such tests in the following words:

> They have shown that fatigue is frequently bound up with the production of various chemical products, some of which, such as sarco-lactic acid, are well-defined chemical substances, whilst others, the so-called "fatigue toxins," are very indefinite and uncertain. Experiment has likewise shown that as a rule the chief seat of fatigue is not in the muscles themselves, as subjective sensations would lead us to infer, or even in the nerves supplying the muscles, but in the central nervous system. Here again fatigue is localized, not so much in the nerve cells, as in the junctions between nerve processes and cells, the so-called *synapses*.

MEASUREMENT OF FATIGUE.—One method of measuring fatigue is, first, to take a production study for an entire day and record the over-all time per piece, delays and interruptions being considered foreign to the study. From this all-day study the time per piece, which will include fatigue, should be computed without adding allowances. Second, when the operator is working without indication of fatigue and at maximum production, time per piece is computed from a time study. After leveling, the difference between the production study time per piece and the time study figure will give the amount to be allowed for fatigue. Very often, by following this method, a reasonable fatigue value, or factor, will be obtained. However, exceptions will be found, for the effect of fatigue varies greatly with the individual's mental and physical make-up. For instance, many persons find monotonous work fatiguing, while others do not; nor does heavy work always induce great fatigue.

Example: A fatigue study.

Number of pieces produced in production study	=	6,810
Total productive time from production study	=	376.9 min.
Time per piece from time study (without allowance)	=	.054 min.
Fatigue factor — $\frac{376.9 - (6{,}810 \times .054)}{6{,}810 \times .054}$	=	2.5%

FACTORY EXPERIMENTS ON FATIGUE.—Pennock conducted studies on fatigue for several years. Small groups of operators were isolated in a test room partitioned off from the main workroom and subjected to various combinations of working conditions changing only one variable at a time. Pennock's conclusion was that mental attitude was by far the dominant factor in the problem. "A relationship of confidence and friendliness has been established to such an extent that practically no supervision is required. They have been relieved of the nervous tension under which they previously worked" (Personnel Jour., vol. 8). Some specific conclusions are:

1. Amount of sleep has slight but significant effect upon individual performance.
2. A distinct relationship is apparent between emotional status or home conditions of girls and their performance.
3. Total daily productivity is increased by rest periods, and not decreased.
4. Outside influences tend to create either a buoyant or a depressed spirit which is reflected in production.
5. Mental attitude of operator toward supervisor and working and home conditions is probably the biggest single factor governing the employee's efficiency.

FATIGUE VARIABLES.—General causes of industrial fatigue have been classified as: (1) poor emotional adjustment; (2) deficient bodily conditions; and (3) improper environmental forces. It is obvious that there are many variables outside the factory which contribute to employee fatigue, but these are largely personal and beyond an employer's direct influence. Of the variables within the factory and those under the employer's responsibility, the following eight are most important. Each is treated separately.

1. Physical demands of job.
2. Nervous demands of job.
3. Noise of work environment.
4. Illumination of workplace.
5. Accident hazards of job.
6. Duration and time of work period.
7. Air conditions of work environment.
8. Monotony of job.

Physical Demands of Job.—When Taylor studied pig iron handling, shoveling, and other "yard" jobs, cranes, hoists, conveyors, etc., had not come into common use. Hence, bodily strength was demanded in a large proportion of factory work. Today light manual or machine jobs predominate in most factories and such jobs do not make heavy demands on muscular strength. Where strength is yet demanded and cannot be eliminated, then the special treatment of frequent rest periods, very high

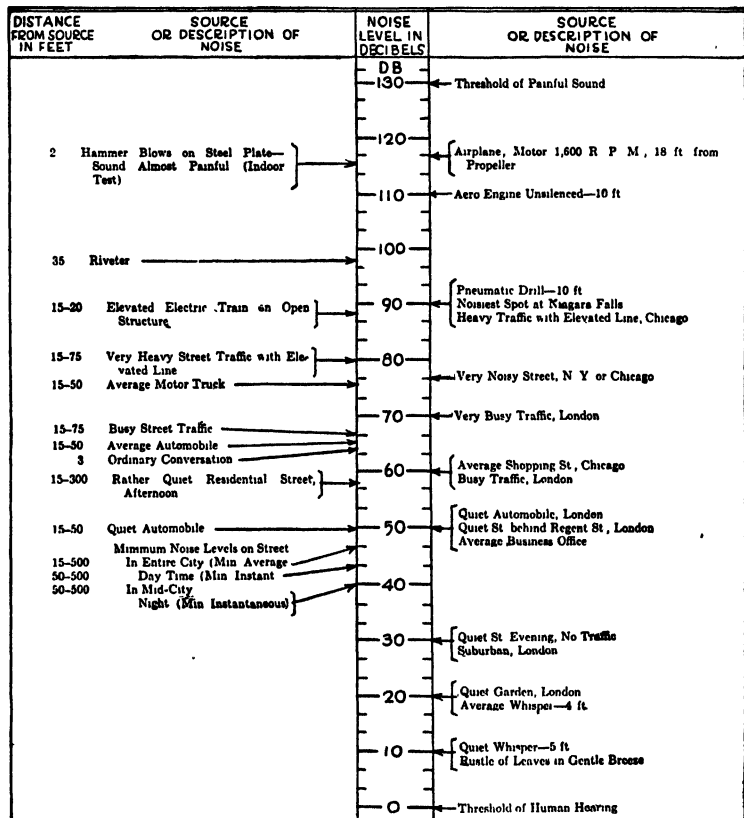



Fig. 25. Noise Levels Out of Doors Due to Various Noise Sources

incentives, etc., must be incorporated. (Taylor, Principles of Scientific Management.)

Nervous Demands of Job.—Badly functioning machines or tools, false economy in material quality, unkind words or looks on the part of a foreman, these and domestic discouragements cause mental irritation and do more to tire employees than any amount of physical exertion. Management cannot usually reach back to the causes on the domestic side but it can reach all on the job side. **Strong incentives,** such as a high piece rate, have made employees more insistent that management maintain standard conditions, but frequently employees endure needless hardships, elimination of which would be to management's interest. Cheap thread for sewing-machine operations is a typical example. A certain manager had always thought he could save money by buying an

Sound Intensity in Decibels	Description of Operation
85	Wire Drawing No. 2 Machines
75	Milling (One Special Job)
	Heading and Slotting (Heavy Machines)
	Heavy Punch Press Operations
	Textile Insulating of Wire
	Wire Drawing No. 1 Machines
70	Multiple Drill Press Operations (Heavy Machines)
	Automatic Screw Machine Operations
	Perforate and Blank on Punch Presses
	Heavy Punch Press Operations
	Die Casting Operations
	Paper Insulating of Wire
65	Straightening Iron Stock
	Loading Coil Winding (Near Machines)
	Drilling (Light Machines)
	Milling (Regular Work)
	Miscellaneous Punch Press Operations
	Hand Screw Machine Operations (Individual Motor-Driven Machines)
	Twisting Light Gage Wire
	Tinsel Manufacture
	Wire Inspection
	Hand Screw Machine Operations (Heavy Type Machines)
	Heading and Slotting (Light Machines)
	Miscellaneous Punch Press Operations
	Heavy Punch Press Operations
	Polishing and Buffing (Heavy Work)
	Magnet Wire Insulating
	Cotton Binding
	Rubber Buffing
60	Molding Brass Foundry
	Cleaning Castings Gray Iron Foundry
	Bench Work on Loading Coils
	Spool Assembly (Bench Work)
	Straightening Frames (Bench Work)
	Hand Screw Machine Operations (Overhead Belt Drive Machines)
	Hand Screw Machine Operations
	Punch Press Operations (Light Work)
	Straightening Frames (Bench Work)
	Miscellaneous Machine Work
	Cable Stranding
	Rubber Molding
55	Molding in Gray Iron Foundry
	Bench Assembly Operations
	Bench Work on Loading Coils
	Tapping Machines
	Hot Tin Dipping
	Extruding Lead Cable and Lagging Cable Reels
50	Assembling Relays
	Wiring Multiple Banks
	Jack and Ringer Assembly (Bench Work)
45	Desk Work (Typing, Filing, etc.)
	Kick Press Operations
40	Wire Balancing
	Desk Work (Typing, Filing, etc.)

FIG. 26. Sound Intensity of Various Operations

inferior grade of thread. He had not known how much time was wasted from thread breaking, rethreading, etc., and employees had not known how much better good thread would work. An analysis of this time waste and of the irritation involved changed the manager's policy and enabled employees to produce more work for the same input of energy. Worst of all is **thoughtlessness of a foreman** who intentionally or otherwise hurts an employee's feelings. He may not even say anything unkind but his look, or manner, or lack of appreciation, can have an identical effect. **Good control of all physical conditions,** together with proper selection and training of foremen, are means of correcting this major cause of needless fatigue.

Noise of Work Environment.—Noise has been increasing in factory work as in all modern life. Fortunately, a public opinion has gradually arisen which is bringing some cessation. A few writers claim that noise has no definite bearing on fatigue, that "employees accustom themselves to it, ignore it, or forget it." Nevertheless it has been recognized by executives as tiring to themselves and it is just as surely tiring to employees. The first step in abatement of noise nuisance is one of measurement. A unit called the decibel has been standardized and an instrument made to register sounds in that unit. The decibel, abbreviation DB, is defined as the smallest change which the ear can detect in the level of sound. It is scaled in ratio of intensities from a zero "threshold." Thus, if two sound intensities are in ratio of 10^2 to 1, they differ by 20 decibels, etc. Fig. 25 shows findings of the Noise Abatement Commission. (City Noise, Dept. of Health, City of New York.)

Compared with the scale of Fig. 25, running from the threshold of human hearing to the threshold of painful sound, Anderson's **measurements of noise** on certain factory machines and operations are instructive. These measurements are given in Fig. 26.

The relative intensity of sound alone does not account for **pitch or quality,** and does not show **regularity or irregularity,** all of which make a difference in the tiring effect. Anderson found that most factory work came between 85 and 40 decibels. Some idea of this upper range may be had from the fact that very loud radio music in a house measures 80 DB and a very noisy restaurant measures 70 DB. Kennedy says:

Noise interferes very seriously with the efficiency of the worker. It lessens attention and makes concentration upon set tasks difficult. The first effect of noise is one of disturbance, of excitation, and of irritation. These effects have consequences of many kinds in conduct. They cause loss of temper, they play a part in quarrels, and they prevent deep and sustained thinking. In attempting to overcome the effects of noise, great strain is put on the nervous system—leading to neurasthenic and psychasthenic states.

The effects of noise have been described by research workers as emotional. However, long before the emotions are actively disturbed there are disturbances by reason of the stress vibrations in heightened pulse rate, heightened blood pressure, some irregularities in heart rhythm, and, most important of all, in the increase of pressure on the brain itself, as our experiments have indicated. Emotion is only the end product of the process; the undoubted effect of constant noise is disturbance of the blood vessel apparatus and the increase in the degenerative processes in the heart and arteries.

The fact that hearing is likely to be impaired in those exposed to loud noises actually brings about a deterioration in the efficiency of the worker that shortens his years of profitable activity. This is another example—a cruel example—of the harmful effects of noise on human beings. Undoubtedly, we should include progressive deterioration of hearing in workers in noisy trades as a work hazard to be compensated by insurance—paid for either by insurance companies or by the employer.

How to Reduce Noise.—"A noise that cannot be prevented or greatly reduced at the source, by design or by damping, will radiate into the air either directly from the surface of the vibrating body, or from the parts of the structure to which it is attached" (Kimball, in Kent's Mechanical Engineer's Handbook, Design, Shop Practice, vol. 3).

Classification of Noise		Method of Prevention	
Preventable at source		Design changes Damping	
Not readily preventable at source	Direct Noise	Screening Absorption Filtration	Higher frequency range, 300 cycles up
	Indirect Noise	Isolation by suspension	Lower frequency range under 300 cycles

Design changes to reduce noise are brought about by manufacturers' studies. Examples are: car wheels—steel rims insulated from the rest of the wheel by rubber; electric motors—special designs producing lower alternating current electric hum; blowers—whistles from blowers in ventilating ducts, usually blade frequency noises, eliminated by design changes; gear whistles—high-speed gearing improved by accurate design to avoid impacts, and using helical instead of spur gears.

Damping by covering with suitable material which reduces vibrations. Putty lagging—layer of nondrying putty 1 in. or more thick, covered with varnished material, or similar material to prevent drying, is good to reduce ringing noises and high frequency whistles. Felt-like materials—less effective than putty, however, sometimes are good as noise reducers.

Screening: By constructing screens or walls highly resistant to noise transmission.

Absorption: Directly radiated noise, such as from office or factory, cannot be screened. Reduction in noise can be made by sound-absorbing materials. Felt-like materials have a high sound-absorbing power as have certain porous materials, for example, celotex.

Filtration: When direct noise, containing definite notes, is transmitted along ducts or through openings, it is possible completely to eliminate objectionable harmonics by an acoustic filter. Example of a high-pass filter is an automobile muffler or Maxim silencer. Space is the usual limitation to such applications.

Isolation by suspension: Forced vibrations may be cured by isolation, through the use of elastic suspension. Spring suspensions, steel, rubber, cork, and gelatin compounds are used.

Illumination of Workplace.—Improper illumination is responsible for from 10% to 15% of the total nervous energy expended in work. The

muscles of the eye are easily tired if required to expand and contract too frequently as is the case where work must be done under strong local lights. General lighting is desirable in that it lessens visual fatigue, mental irritation, and uncertainty of movement, and adds to pleasantness of surroundings if not actually to quality and to safety of work. Adjustable window coverings should be installed on all windows through which the sun shines, to avoid excessive heat and glare. Standards for intensity of artificial illumination have been set for practically all the different kinds of work and should be lived up to for maximum production.

Accident Hazards of Job.—There are more industrial accidents during January, February, and March than during other months of the year. If such increases were solely due to the lack of daylight, the period ought to extend over November and December. Anderson points out that a better correlation may be found with the trend of health, that is, periods of high accidents and prevalence of respiratory diseases are identical. There is no evidence that fatigue from work could cause this seasonal increase. Neither is there evidence that fatigue due to summer heat is a general cause of accidents. In fact, Anderson found that the **accident frequency rate parallels production rate.** For instance, during any one day the hour between 11 A. M. and 12 M. showed fewer accidents than any other hour in the morning, and the hour between 4 and 5 P. M. showed fewer accidents than any other hour in the day. No matter how much fatigue may contribute to a let-down in production, it evidently does not contribute to accident frequency. Studies of Anderson may not be typical in this respect, but they cannot be wholly exceptional. In the matter of work experiences his findings are consistent with what might be expected. "Inexperience is obviously a big factor in accident causation as evidenced by a rapid decrease in the accident rate for new employees. An analysis by age of employees reveals a decided downward trend as the age limits increase. Accidents at night are relatively more frequent than in day time, probably in part due to poorer lighting."

Duration and Time of Work Period.—With shortening of both work day and work week in the United States, there is no longer any general undue fatigue effect from long work hours except where overtime is required. Neither is there any serious danger that overtime will be used beyond real necessity. **Night work** remains, however, a considerable problem to many concerns. In busy times it is good plant economy to operate on more than one shift. By paying a slightly higher rate per hour, operatives can be induced to take night-shift work. In the past, night shifts were often longer than day shifts and badly managed, that is, foremen themselves connived at long intervals for sleep. If night shifts become the rule, not the exception, they will be as short and as well managed as day work. The difficulty then will be partly in the worker's failing to get adequate sleep during the day time, and partly in the less stimulating nature of artificial light, etc. Anderson found, however, that under proper conditions the output at night was as high and as uniform as in day work. "The downward trend in production rate toward the end of the night shift was in general about the same or less than in the day shift, and accounted for by other factors than fatigue."

Air Conditions of Work Environment.—Much factory work is done in bad air. Ignoring that portion which is due to location, and to the season of the year—Anderson found that the **loss of production due to excessive summer temperature** was generally around 2%, rarely over 5%, and that that was partly due to disturbed sleep and to wrong eating, or unavoidable requirement of the manufacturing process. One writer cites several examples, only the last item of which would seem entirely beyond correction. These cases, although exceptional, were found in one of the best factories.

Date	Temperature in Degrees F.	Humidity in Per Cent	Kind of Work
February	100	38	Punch Press
April	87	12	Hot Plate
May	108 – 115	32	Copper Casting
May	100 – 115	–	Copper Charging
June	110 – 116	39	Copper Casting
June	220 – 250	0	Vacuum Drying (Brief Periods)

Measurement and control of humidity have been undertaken where the product required conditioned air, but rarely otherwise except in offices. Fortunately, much can be done without expensive air-conditioning equipment.

It must be emphasized that the avoidance of overheating is the primary essential in all systems of ventilation. Air change, direction of flow, and all other factors are secondary. The most important item of ventilating equipment is the thermometer; and however simple or however complex an apparatus may be installed for air conditioning, a constant and intelligent vigilance in regard to operating and overheating is the price of health and comfort. (Ventilation, New York State Commission Report. See also Winslow, Fresh Air and Ventilation.)

Monotony of Job.—While it is true that more complaints of monotony arise where work cycles are short and where the rate of production is wholly or partially set by machines, yet it is becoming evident that effects of monotony depend largely upon the minds of operatives. Certain individuals find relatively long cycles of work monotonous, while other individuals do not find even the shortest cycles monotonous. Anderson found only a few instances of "obvious distaste for work due to monotony." The facts that conveyors are set for average human speed, as is necessary in group work, and that physical strain is practically eliminated by conveyors, compensate most operatives for whatever tendency there may be toward monotony in typical mass production work.

The counterpart of monotony, interest in work, has always been difficult to understand. It may depend upon variety of work, upon difficulty in getting operations done right, upon some pleasing quality of material such as color or smoothness, upon importance of work, as in war-time production, or merely upon ease or cleanliness of work. It is certainly **an individual matter** and must be approached accordingly. One of the few satisfaction factors which is common to most individuals is sociability, the possibility of being among friends and of conversing with them periodically if not continuously. The typical mass production job allows, in fact facilitates, this social contact. The fallacious thinking of

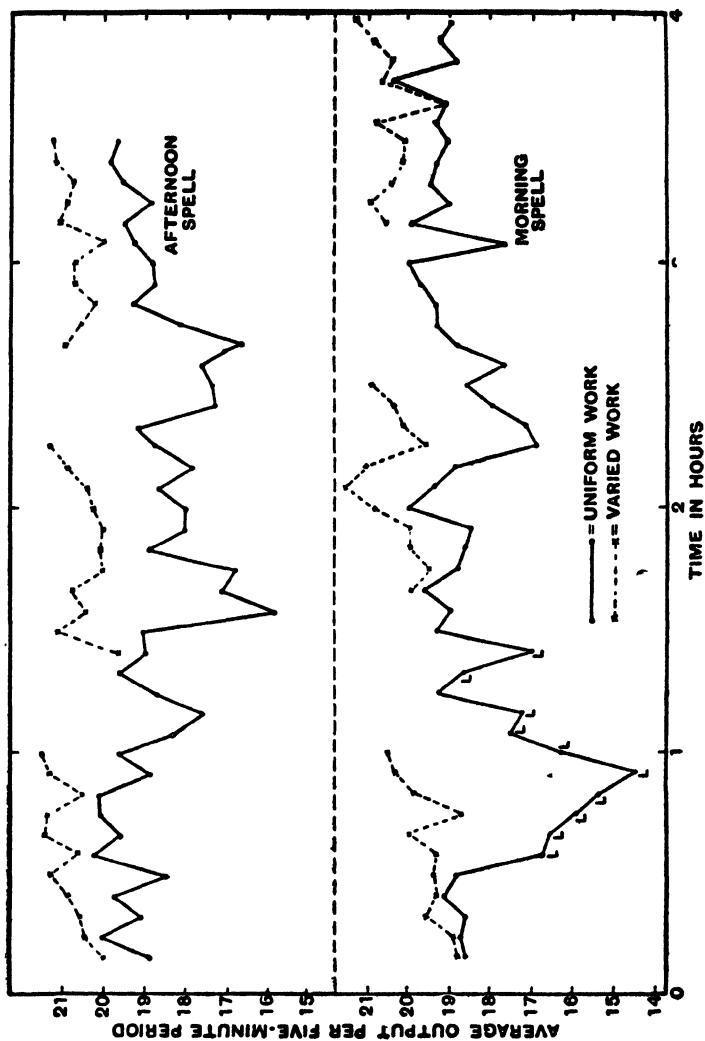



FIG. 27. Variations in Output Under Uniform and Varied Procedures—Cigarette Making

many social reformers on monotony is doubtless due to generalization from their own unrepresentative individualities.

CHANGE OF WORK AFFECTS OUTPUT.—Uniformity in working procedure is more monotonous than variety as shown by results obtained in the process of making cigarettes by hand (Great Britain, Indus. Health Res. Board Reports 56 and 52). Twenty operators were employed for certain days, exclusively on the continuous and uniform operation of filling; on other occasions the filling operation was continued for an hour, followed by cutting. The output curve obtained from these two methods is shown in Fig. 27. The curve for the varied method of procedure is at an approximately 9% higher level than that for the uniform method. Points marked "L" mean that one or more of the girls took lunch. On days of varied work lunch was taken during the cutting process.

PERSONAL AND INCIDENTAL TIME.—Because of the cumulative nature of fatigue, it is natural for workers to seek relief in pauses of various kinds. If there is incidental work to be done, that is, legitimate work but work not directly productive, they will do this intermittently and sometimes prolong it. They will go for a drink of water, for a tool, etc., all of which make disagreeable jobs tolerable and most jobs more enjoyable. It is only the abuse of such respites that needs to be restricted.

In a study of 8,300 hours of work without rest periods, covering men and women workers and machine and manual operations, Anderson found that the average time taken for personal use was 3.6%, and for incidental use 8.7%. In a study of 2,973 hours of work under the same plan but with rest periods, the average time taken for personal use was 1.8% and for incidental use 5.4%. Where waiting time was necessary to the extent of 11.4% on the average, average time taken for personal use was only 1.2% with no time taken for incidental use. He also noted what is well known, that there was a tendency to ease up toward the end of each half-day, particularly in the afternoon, if the task were sure of completion. His conclusion was that "the work hours are not hours of continuous, intensive effort; that from 12% to 15% or more of the time is used for rest or for duties incidental to the main task. This finding helps to explain the general lack of fatigue effect of shop operations."

REST PERIODS.—Enforced rest periods have come into common use in order that sufficient pause from work may be assured and in the hope that excessive time out from other causes may be reduced. Physical fatigue has been so far eliminated from typical factory jobs of today that such rest periods would not be very important were it not for the nervous or mental fatigue which remains common, and may possibly be increasing. Rest periods are good psychology, that is, they offset monotony and give something not far ahead to anticipate. The usual practice is to stop machinery for 10 or 15 minutes in the middle of each half-day. For hazardous or extremely exacting work a greater number of shorter periods is suitable, such as five minutes out of every hour. In general, it is found that where rest periods are used, less time is taken out for personal use and more production is made during the last hours of each half-day. Production per day may be increased slightly, but in the case

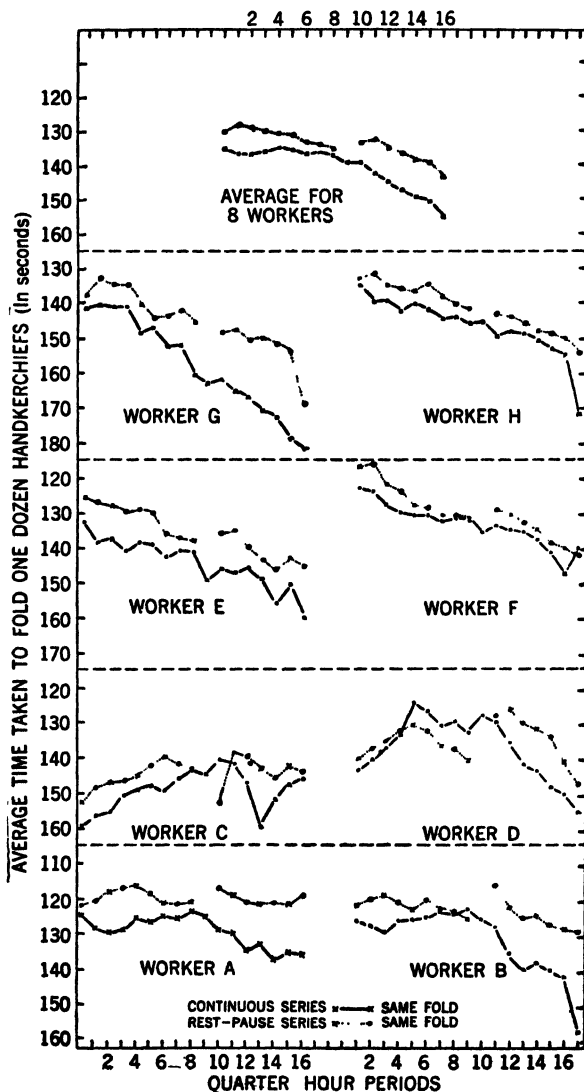



FIG. 28. Variations in Average Times in Handkerchief Folding Under Continuous and Rest-Pause Operations

of automatic machine jobs it may be decreased. In any case, workers like rest periods and have better morale with them.

Effect of Rest Periods on Production.—Observations were made of eight girls engaged in folding handkerchiefs (Great Britain, Indus. Fatigue Res. Board Report 32). They were all experienced. Each operator was observed for 3 weeks when continuously employed on the same kind of fold, afterwards she was observed for a similar period in which a rest of 10 min. was given from 3.30 to 3.40 P M. Hours of work were from 7.45 A.M. to 12.15 and from 1.15 to 5.30 P.M. Operators were paid on a piece-rate basis. Observations were limited to the afternoon, as the manager wished to try the effect of a rest period then. A rest period was already in effect in the morning.

Rate of work was increased on an average of 5.0%; the maximum increase for any one operator was 6.5% (E) and the minimum increase 2.7% (F) (Fig. 28). Net average increase in hourly output was approximately 1%.

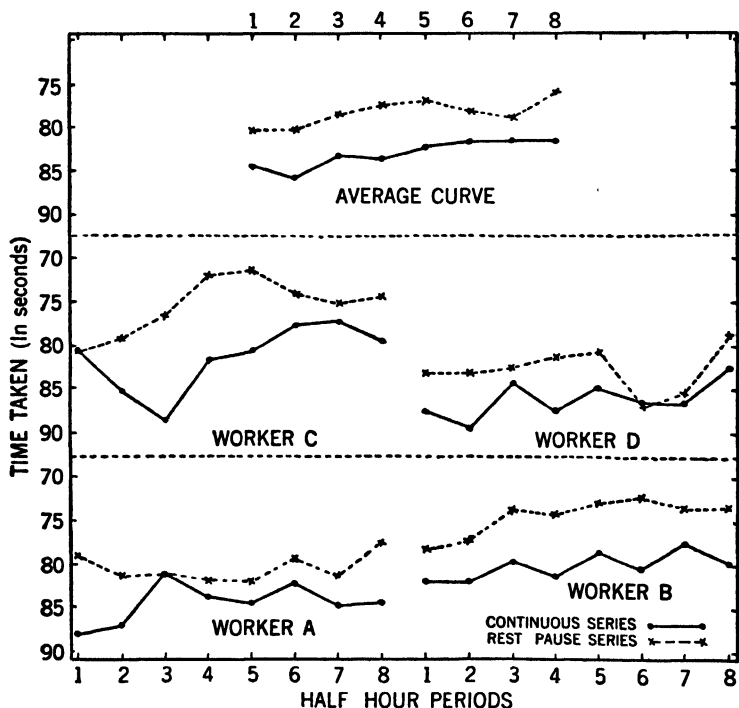



Fig. 29. Variations in Average Times in Handkerchief Ironing Under Continuous and Rest-Pause Operations

Another comparison of effect of a rest period on rate of working was made on handkerchief ironing. Time to iron a dozen handkerchiefs was noted as frequently as possible throughout each afternoon (Fig. 29). A correction was made when necessary to dampen the handkerchiefs before ironing (Great Britain, Indus. Fatigue Res. Board Report 32). The average increase in rate of working for all operators was 6.1%; the maximum increase for any one worker was 7.8% and the minimum 4.0%. Net average increase in hourly output was approximately 2%.

The spinning department of a Pennsylvania textile mill had a 250% labor turnover in a year. In other departments the turnover was 5%. Workmen in the spinning department complained of neuritis, foot trouble, and melancholia. The effect of establishing rest periods (Fact. Mgt. & Maint., vol. 95) of 10 min. out of every 2 hr., when everyone was required to lie down and relax, was to eliminate complaints and increase production so that bonuses were earned, and, at the end of the first year of this procedure, there had been practically no labor turnover.

NOURISHMENT REDUCES FATIGUE.—By eating five meals a day, if in normal health, an active individual may increase his energy and work efficiency, according to experiments of Dr. Haggard of Yale University (Mech. Eng., vol. 58). During a test in a shoe factory, on a group of 20 operators, who had been averaging 175 shoes an hour when they had eaten three regular meals a day, two extra meals, consisting of milk and cake, were given. Production jumped to 193 shoes, or approximately a 10% increase. The operators commented on the fact that they felt less tired on the days when they were given the extra meals.

Analysis and Synthesis of Job Data

DETERMINATION OF BASE TIMES.—Base times are the observed times from the study before grading or leveling and before allowances have been added.

Working up data and determination of base times should be done, preferably by the observer while all details are fresh in his mind.

ARITHMETIC AVERAGE BASE TIME.—The sum of observed times for an element, divided by the number of observations, gives the average time. An observation may be omitted from the average when there is a definite, valid reason for doing so. Fig. 30 reproduces a time study where the base time is computed as an arithmetic average.

The arithmetic average is easily and quickly computed, and the figure can be readily explained to the operator. However, judgment is necessary in leveling or grading. The plan is extensively and successfully used throughout industry.

STATISTICAL METHODS OF DETERMINING BASE TIME.—During the early development of time study considerable stress was put on statistical methods of adjusting time study data to obtain base times. Among these possibly the best known was Merrick's statistical determination of base time. This method has now fallen into disuse. At the present time, while there is some disagreement between the proponents of leveling (Lowry, Maynard, and Stegemerten), effort

TIME STUDY SHEET

PLANT New York University **APP. CODE & PIECE PART** Soft Steel Part 1" x 1" x 3/16" **OBSERVER** J. G.

DEPT. Administrative Engineering **ORDER** **OPERATION** Drill one hole (.173" diam.) **DATE** 10/29/-

ELEMENTS	ENDING	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	NOTES Totals	Average
Pick up piece, place in jig, tighten jig.	Hand Leaves clamp	08 08	08 55	07 1.04	10 58	06 2.04	05 47	05 89	10 42	06 85	07 29	08 75	06 25				.86	.072
Turn jig, place in position oil drill, drill down	Drill touches work	17 25	18 73	15 19	15 73	13 17	15 62	16 3.05	13 55	15 4.00	13 42	12 87	13 38				1.75	.146
Run 3/16" + Lead DRILL 1800 r.p.m.	Drill comes through	10 35	11 84	16 35	12 85	12 29	10 72	15 20	13 68	12 12	15 57	19 5.06	15 53				1.60	.133
Drill up, clean chips, Loosen piece, place in box	Hand leaves tote box	12 47	13 97	13 48	13 98	13 42	12 84	12 32	11 79	10 22	10 67	13 19	11 64				1.43	.119 .470
Walk 12 ft. to bench, return with work, take position								79 min. for 50 pcs. .79/50 = .016										
Study	Computations																Skill + .03 Effort + .02	
Average Base Time, Min. per Piece						.494											Conditions 0 Consistency 0	
Pers. Fatigue, and Delay Allowance at 11%						.054											+ .05 +1.00 = 1.05	
Working Cycle, Min. per Piece						.548											.470 x 1.05 = .494	
Preparation Time, Min. .016 plus 20%						.019												
Standard Time, Min. for 1 piece						.567											Jig #37519	
Hourly Production						106											#17 drill H.S.	
Base Rate $ .60 Incentive	25% Earning Rate					$.75											Speed F.P.M. = 81	
Piece Work Price per 100						$.71												

FIG. 30. Time Study Sheet with Study Computations

rating (Carroll, Presgreave), and speed rating (Shumard and others), all agree that mathematical methods of adjusting time study data are meaningless. The Committee on Rating Time Studies, working under the auspices of The Society for the Advancement of Management, has discarded from further consideration all mathematical methods in favor of those which require the observer to judge the performance given by the operator. The older mathematical methods thus have value only in their historical significance.

SKILL AND EFFORT.—The relative skill of the operator observed is an important factor which must be taken into account in setting the task on the job for an average worker. It is difficult to define skill. A definition proposed by Dr. Lillian M. Gilbreth (Mech. Eng., vol. 58) is: "Skill is dexterity, plus knowledge, which can adapt itself to changing situations and is capable of improvement."

This definition is broad and includes method in its meaning. In the leveling of time data the word "skill" is used in a narrow sense as "proficiency in following a given method." "Effort" is defined as "the will to work."

LEVELING AND RATING.—It is obvious that the time taken per cycle by one operator will vary from the time taken by another operator because of differences in the two operators' rates of working and differences in conditions existing at time of study. Even during one study such variations often occur. The operator's time may be affected by his physical condition and mental attitude, or by conditions beyond his control, such as material or equipment variations. The latter should be controlled and maintained as standardized for the job, before the

Skill			Effort		
+.15	A_1	Superskill	+.13	A_1	Excessive
+.13	A_2		+.12	A_2	
+.11	B_1	Excellent	+.10	B_1	Excellent
+.08	B_2		+.08	B_2	
+.06	C_1	Good	+.05	C_1	Good
+.03	C_2		+.02	C_2	
0	D	Average	0	D	Average
−.05	E_1	Fair	−.04	E_1	Fair
−.10	E_2		−.08	E_2	
−.16	F_1	Poor	−.12	F_1	Poor
−.22	F_2		−.17	F_2	

Conditions			Consistency		
+.06	A	Ideal	+.04	A	Perfect
+.04	B	Excellent	+.03	B	Excellent
+.02	C	Good	+.01	C	Good
0	D	Average	0	D	Average
−.03	E	Fair	−.02	E	Fair
−.07	F	Poor	−.04	F	Poor

Fig. 31. Rating Scales for Leveling Time Study Observations

DATE 12-2- STUDY NO. 1 SHEET NO. 1 OF 1 SHEETS

ELEMENTS	Get stud from table and place in chuck		Tighten chuck with socket wrench		Start machine		Face stud		Turn turret one position		Point stud		5	
NUMBER	1		2		3		4		5		6			
LINE	T	R	T	R	T	R	T	R	T	R	T	R	T	R
1	18	18	19	37	3	40	38	78	14	92	10	102	10	12
2	21	68	20	88	4	92	34	326	12	38	11	49	12	61
3	20	28	20	48	4	52	48	600	10	10	10	20	12	32
4	25	802	16	18	3	21	45	66	12	78	9	87	11	98
5	19	73	20	93	3	96	–	M	–	M	–	M	–	1184
6	25	43	19	62	4	66	46	1412	11	23	11	34	9	43
7	23	23	(10)	33	3	36	40	76	11	87	12	99	9	1708
8	A 18	2330	15	45	4	49	47	96	14	2410	8	18	12	30
9	20	94	20	2614	3	17	30	47	10	57	9	66	10	76
10	18	36	19	55	3	58	34	92	10	2902	10	72	11	23
11	18	110	17	27	(2)	29	31	60	12	72	10	82	11	93
12	B 25	430	(43)	73	3	76	38	514	13	27	9	36	11	47
13	21	813	14	27	3	30	46	76	11	87	10	97	9	906
14	28	80	D 19	1137	3	40	33	73	11	84	(6)	90	12	1202

ELEMENTS	Turn stud		Turn turret two positions		Chamfer hex		5		Thread stud		5		Stop machine		Remove stud and place in tote pan	
NUMBER	7		8		9				10				11		12	
LINE	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R
1	40	52	12	64	14	78	14	92	18	210	10	20	14	34	13	47
2	45	406	12	18	17	35	11	46	26	72	10	82	13	95	13	508
3	46	78	12	90	13	703	11	14	21	35	11	62/51	16	51/35	15	77/62
4	50	948	11	59	16	75	10	85	28	1013	11	24	18	42	12	54
5	41	1225	12	37	11	48	12	60	19	79	11	90	17	1307	11	18
6	41	84	11	95	11	1506	11	17	25	42	10	52	14	66	(34)	1100
7	46	54	13	67	(7)	74	10	84	28	1812	–	–	–	–	–	–
8	38	68	14	82	12	94	10	2504	24	28	16	44	18	62	12	74
9	41	2717	11	28	15	43	12	55	23	78	11	89	16	2805	13	18
10	51	74	15	89	15	3004	12	16	32	48	12	60	(22)	82	10	92
11	46	239	11	50	14	64	10	74	29	303	12	15	18	33	(8)	41
12	46	93	11	604	9	13	11	24	22	46	14	60	11	71	C 12	792
13	42	48	11	59	(21)	80	12	92	20	1012	12	24	16	40	12	52
14	45	47	11	58	–	M	–	M	–	1301	14	15	18	33	11	44

SUMMARY

	1	2	3	4	5	6		7	8	9		10		11	12
Totals "T"	.0299	.0218	.0043	.0510	.0590	.0119		.0618	.0167	.0147		.0315		.0189	.0134
No. Observations	14	12	13	13	52	12		14	14	11		13		12	11
Average "T"	.00214	.00182	.00033	.00392	.00116	.00099		.00442	.00119	.00134		.00242		.00158	.00122
Minimum "T"	.0018	.0014	.0003	.0030	.0009	.0008		.0038	.0011	.0009		.0018		.0011	.0010
Maximum "T"	.0028	.0020	.0004	.0048	.0016	.0012		.0051	.0015	.0017		.0032		.0018	.0015
Ratings (S E C Cy)	B1B1BC	B2B2CC													B1B1BC
Leveling Factor	1.26	1.19													1.26
L.F. × Ave. "T"	.0027	.00217	.00035	.00451	.0014	.00122		.00508	.0014	.00157		.00278		.0019	.00155
% Allowance	15	15	15	10	15	15		10	15	15		10		15	15
Time Allowed	.0031	.0025	.0004	.0054	.0016	.0014		.0056	.0016	.0018		.0031		.0022	.0018

FOREIGN ELEMENTS

SYM	R	T	DESCRIPTION
A	2312 / 1812	500	Break stud
B	405 / 341	64	Get 14 studs
C	780 / 671	109	Get drunk
D	1123 / 1085	38	Drop wrench wipe hands
E			
F			
G			
H			
I			

SKILL			EFFORT		
	A1 / A2	SUPER		A1 / A2	EXCESSIVE
✓	B1	EXCELLENT	✓	B1	EXCELLENT
✓	B2		✓	B2	
	C1 / C2	GOOD		C1 / C2	GOOD
	D	AVERAGE		D	AVERAGE
	E1 / E2	FAIR		E1 / E2	FAIR
	F1 / F2	POOR		F1 / F2	POOR

CONDITIONS			CONSISTENCY		
	A	IDEAL		A	PERFECT
✓	B	EXCELLENT		B	EXCELLENT
✓	C	GOOD	✓	C	GOOD
	D	AVERAGE		D	AVERAGE
	E	FAIR		E	FAIR
	F	POOR		F	POOR

GENERAL RATING FOR STUDY	SKILL	EFFORT	COND	CONS.

STUDY STARTED	STUDY FINISHED	OVERALL TIME
8.46 A.M.	9.12 A.M.	.433 HRS.

FIG. 32. Time Study Observation Sheet with Allowed Time for Each Element Computed Separately

OBSERVATION SHEET

STUDY No. 1 DATE 12-2-
OPERATION Face, Point, Turn and Thread Short End of Stud
DEPARTMENT F-1 OPERATOR Man/Woman NAME Domer No. 209
EQUIPMENT #5 Turret Lathe
MACHINE TOOL No. 4689
SPECIAL TOOLS JIGS FIXTURES ETC
CONDITIONS Excellent. Machine had been recently repaired.
OBSERVER A. B. Sea APPROVED BY John Doe
SKETCH

MOULD Forge DIE #55433 DWG. 285792 SUB. 8
STYLE 284894 ITEM 2
PATTERN INS SPEC L SPEC SUB
PART DESCRIPTION Stud for Type 214-A Control Box
MATERIAL Hard drawn 5/8" Hex. copper rod

No.	ELEMENTS	SMALL TOOL NOS. FEED SPEED, DEPTH OF CUT, ETC.	ELEMENTAL TIME ALLOWED (BOTTOM LINE OTHER SIDE)	OCCURRENCES PER PIECE OR CYCLE	TOTAL TIME ALLOWED
1	Get and place stud in chuck				.0028
2	Tighten chuck				.0024
3	Start machine				.0004
4	Face stud	900 R PM. Forged tool			.0052
5	Turn turret-one position	(Hand feed)	.0015	4	.0060
6	Point stud	900 R PM. Box tool			.0013
7	Turn stud	900 R PM .015"/Rev. Box tool			.0056
8	Turn turret-two positions				.0016
9	Chamfer hex	900 R PM Hand feed Forged tool			.0018
10	Thread stud	300 R PM Die			.0031
11	Stop machine				.0021
12	Remove stud				.0016

TIME ALLOWED, SET UP EACH PIECE TOTAL .0339 hr.

REMARKS: Due to turret construction, it takes no longer to turn turret two positions than it does to turn it one position

Fig. 33. Reverse Side of Sheet in Fig. 32 with Allowances Computed for Each Element Transferred

study is taken. An adjustment of the time study time is made to level it to the time an average operator should take.

One widely used leveling plan (Lowry, Maynard, and Stegemerten, Time and Motion Study, 1940 ed.) rates the factors of skill, effort, consistency, and conditions at the Westinghouse Electric & Manufacturing Co. The rating scales are shown in Fig. 31.

The observer judges the skill, effort, and consistency of the operator, and the conditions, checking off each item on the leveling chart. For instance, if skill is B_2 (+.08), effort B_2 (+.08), conditions C (+.02), and consistency C (+.01), the sum of these, or .19, would be the leveling factor applied to the average times for each element. All elements are not necessarily given the same grading, for the observer may decide to grade certain elements differently from the general grading applied to the study as shown in Figs. 32 and 33 (Am. Mach., vol. 82). In using "leveling" it should be borne in mind that the accuracy of the final standard is no greater than the accuracy of the observer's judgment. One aid to the observer's judgment of skill is the record of the operator's length of experience on the class of work or the particular job. The operator's diligent application to work at hand with no unnecessary delays or interruptions is an indication of good effort, the value of which must be judged by the observer. Variations from conditions previously standardized for the job are allowed for in the leveling. Consistency of operator may be determined while the study is in progress, or later from the observations. It should be remembered that use of high or low figures on the leveling scale introduces greater chance of error, and in those cases it is better to restudy the job on another operator.

Rating operator's time for speed alone is another adjustment method in general use. It has the advantage of simplicity, but it also is dependent on judgment. Usually each element is individually rated. Shumard (Primer of Time Study) gives a rating table:

Symbol	Speed	Symbol	Speed
100	Superfast	65	Good −
95	Fast +	60	Normal
90	Fast	55	Fair +
85	Fast −	50	Fair
80	Excellent	45	Fair −
75	Good +	40	Poor
70	Good		

Data from a time study on an operator working "good +" for elements a and c, and "normal" for element b, is:

a – Pick up piece, place on bench = .050 min., average time per pc.
b – BURR piece with file = .270 " " " " "
c – Place piece in tray = .030 " " " " "

a .050 time 75 rating or .050 × 75/60 = .063 rated time
b .270 " 60 " " .270 × 60/60 = .270 " "
c .030 " 75 " " .030 × 75/60 = .038 " "

Elements a and c were judged to be performed 75/60 or 25% faster than normal. The operator performing at 60 on element b is producing at normal speed, equivalent to unstimulated day work effort and the time does not have to be adjusted.

ADDED TOTALS ARE EQUAL TO THE WORK CYCLE TIME

TIME OF MOVEMENTS CHART

TIME IN DEC MIN

BODY MEMBER MOVED	TYPE OF MOVEMENT	MOVED AT	MEASURE MOVEMENT OF	IMPULSE PRESS NERVE MIND	DISTANCE MOVED							
					0" TO 2"	4"	6"	8"	1'	1½'	2'	2½'
					5°	10°	15°	20°	30°	45°	60°	90°
FINGER	HINGE	KNUCKLE	FINGER TIP	0015	0017	0021						
FINGER	SIDE	KNUCKLE	FINGER TIP	0021	0032							
HAND	HINGE	WRIST	FINGER TIP	0020	0022	0025						
HAND	ANGULAR	WRIST	FINGER TIP	0022	0032	0038						
FOREARM	ANGULAR	ELBOW	KNUCKLE	0023	0027	0030	0033	0036	0041			
FOREARM	HINGE	ELBOW	KNUCKLE	0018	0020	0022	0024	0027	.0031			
FOREARM	ROTATE	ELBOW	KNUCKLE	0020	0022	0024	0026	0028	0032	.0038	0045	.0053
FOREARM	TWIST	ELBOW	KNUCKLE	0018	0018	0019	0020	0021	0023	0025	0028	0032
ARM	ANGULAR	SHOULDER	KNUCKLE	0029	0030	0035	0040	0048	0060	0080	0095	0105
ARM	ROTATE	SHOULDER	KNUCKLE	0032	0034	0039	0045	.0054	0067	0090	0107	0118
ARM	TWIST	SHOULDER	KNUCKLE	0020	.0022	0025	0027	0028	.0029	0030	.0032	
HEAD	HINGE	NECK	NOSE	✓	0059	.0061	.0063	0065	0069	0075	0087	.0100
HEAD	TURN	NECK	NOSE	✓	0051	0053	0055	0057	0063	0070	0078	0090
FOOT	HINGE	ANKLE	TOE	0024	0027	.0032						
FOOT	ANGULAR	ANKLE	TOE	0028	.0031	0036						
FORELEG	HINGE	KNEE	TOE	0036	0040	0043	.0047	.0052				
FORELEG	SIDE	KNEE	TOE	0040	.0045	0050	0056	0064				
FORELEG	ANGULAR	KNEE	TOE	.0045	.0051	.0057	.0064	.0072				
THIGH	HINGE	HIP	KNEE	.0036	0038	0040	0042	0050				
THIGH	SIDE	HIP	KNEE	.0040	0045	.0050	0056	0064				
THIGH	ANGULAR	HIP	KNEE	.0046	.0052	.0058	0068	0080				
LEG	HINGE	HIP	TOE	0030	0032	0034	0036	0038	0043	0050	0058	0065
LEG	SIDE	HIP	TOE	0045	0048	0052	0056	.0060	.0068	0080		
LEG	ANGULAR	HIP	TOE	.0050	.0052	0056	0060	.0065	.0072	0084	0096	0108
OPERATOR	TURN	HIP OR ANKLE	SHOULDER	✓	.0062	0076	0088	0095	0106	.0120	.0136	0160
OPERATOR	TURN	MOVE FEET	SHOULDER	✓	✓	✓	✓	.0200	.0210	0220	0226	0230
OPERATOR	BEND	HIP OR ANKLE	SHOULDER	✓	0077	.0087	0095	.0102	0111	.0125	0142	.0168
OPERATOR	SIT	HIP	SHOULDER	✓	0180 TO .0210							
OPERATOR	STAND	HIP	SHOULDER	✓	0220 TO .0280							
EYE	MOVE SIGHT	SOCKET	PATH ANGLE	✓	0050	0055	.0059	0062	.0066	0073		
EYE	FOCUS	GET IMAGE CLEAR		✓	0020 TO .0040							
EYE	INSPECT	READ		✓	.0035 TO 0045							
EYE	INSPECT	SEE PART		✓	0025 TO 0035							
EYE	INSPECT	OBSERVE (GLANCE)		✓	.0015 TO 0025							
NERVE REACTION		EYE TO BRAIN OR REVERSE		.0003								
NERVE REACTION		HAND TO BRAIN OR REVERSE		.0024								
NERVE REACTION		KNEE TO BRAIN OR REVERSE		0026								
NERVE REACTION		FOOT TO BRAIN OR REVERSE		0030								
NERVE REACTION		REALIZE CONTACT		.0010 TO .0040								
NERVE REACTION		HEAR OR SMELL		0025 TO 0040								
MIND DECISION		MENTAL PROCESS		0010 TO .0100				NOT OVER .0100				

BODY MEMBER MOVED	TYPE OF MOVEMENT	MOVED AT	MEASURE MOVEMENT OF	PER STEP AFTER 5 STEPS	1 STEPS	2 STEPS	3 STEPS	4 STEPS	5 STEPS	8 STEPS	10 STEPS
OPERATOR	WALK										
OPERATOR	WALK	HIP	6" STEP		0160	.0260	0350				
OPERATOR	WALK	HIP	12" STEP		0210	0330	0440	0530	0610		
OPERATOR	WALK	HIP	18" STEP	.0070	0240	0370	0490	0580	0640	.0850	0990
OPERATOR	WALK	HIP	24" STEP	.0075	0260	0400	.0530	0630	0720	.0945	.1150
OPERATOR	WALK	HIP	30" STEP	.0080	0270	.0420	.0560	.0670	.0770	.1010	1170

NOTE –
USE CIRCULAR MEASURE
FOR UNDERLINED VALUES

Fig. 34. Time for Body Member Movements

Shumard says, "From compiled industrial data covering many plants that have attractive wage payment incentive plans which result in excellent quality of product at low unit costs, it was learned that group average speed of the operators in each plant was 33⅓% faster than normal. . . . Consequently we may safely set up 80 as the ideal effort-goal in manufacturing," the 80 being 133⅓% of 60, normal. This condition, however, will not hold true in all cases.

Another method of leveling, used by Holmes (Applied Time and Motion Study), is to compare the movements necessary to perform an operation with the times previously determined upon as standard or correct times, and, if the study times are too long or short, to use the correct times. These differences may be due to the operator's working too slowly or too rapidly, or to incorrect movements, or to using unnecessary movements. Holmes' times for body member movements are given in Fig. 34.

INTERPOLATION AND EXTRAPOLATION OF BASE TIMES.—In timing similar operations on a range of sizes of the same product, it is usually possible to determine some of the times by interpolation. A few sizes are selected at suitable intervals and their base times plotted. If there is no variation in conditions, an even curve can be drawn through the points, and base times for intervening sizes may be safely interpolated. The principle can also be extended to sizes smaller or larger than those studied, i.e., by extrapolation, but with much less confidence. The danger in both cases is that with certain sizes sudden changes of condition may enter, changing the operation, as for

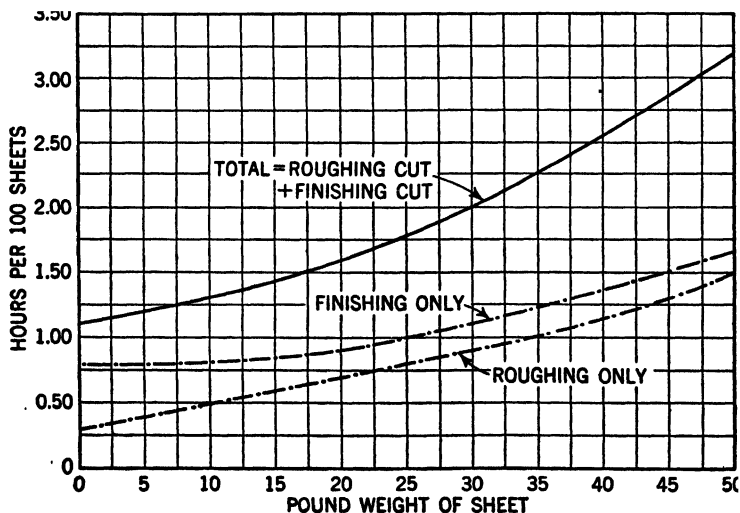



FIG. 35. Curve for Interpolating Times on Sheet Copper Work

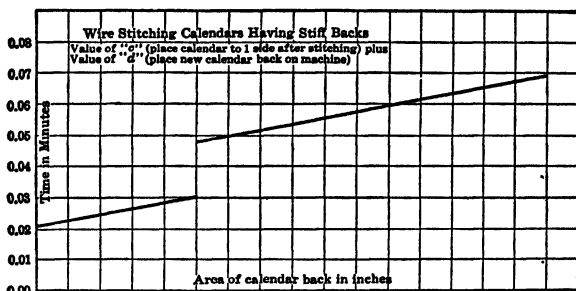



FIG. 36. Curve Showing Sudden Break Due to Change in Conditions

instance, introduction of crane service. Such factors alter time abruptly. When this change of condition is known, sizes just above and below should be studied and discontinuity determined. See Figs. 35 and 36.

NUMEROUS KINDS OF DELAYS.—Certain allowances must be added in **figuring the standard task.** There is a difference between the work a man can do for short times and what he can maintain. There is a variation between the daily production of a good worker and that which would result from his rate at times during the same day. Taylor (Shop Management) defined a full day's work for a first-class man as ". . . what a good man can keep up for a long term of years without injury to his health, and become happier and thrive under." The standard task time must be such that a worker can maintain it indefinitely and thrive. The allowances fall into categories of personal and fatigue allowances and delay times. **Classification of delay times** into avoidable and unavoidable is important. The former should be eliminated and the latter provided for by percentage allowances in setting task and rate. Some of these allowances are discussed below.

Personal, Fatigue, and Delay Allowances.—Personal allowances cover the time it is necessary to allow every worker for his personal necessities. They may range from 3% to 5%, varying with individuals, but tending to be higher when the work is heavy or unpleasant.

High allowances for fatigue are seldom needed. This is because most factory jobs are now performed by methods and under working conditions which minimize fatigue, so that it is not a factor tending to limit production. For light manufacturing work an average allowance of 3% is common practice. Where the work is severe, the proper allowance should be determined for each individual job.

Delay allowances may be avoidable or unavoidable. Avoidable delays are not included in job times. While incidental interruptions, and minor delays from tool breakage, machine stoppages, variations in material, and supervisory contacts should be held to a minimum, they do take place, and these unavoidable delays should be covered by an allowance determined by careful observation and study.

H. B. Maynard, from experience, production studies and analyses of incentive earnings, concludes that an over-all allowance of from 10%

to 15% on ordinary factory work is sufficient to cover fatigue, personal, and unavoidable delays.

RATIO-DELAY STUDY.—In searching for a better way than by taking production studies to determine delay and variation allowances, Lynch, Isaacson, and Schaeffer, under direction of the Department of Administrative Engineering at New York University, put to practical tests, in three separate industries, a method used by Tippett in the English textile industry (Jour. Textile Inst. Trans., Feb. 1935).

These studies show the method to be a statistical technique, highly practical, and productive of more nearly accurate results at less cost than methods which were previously employed. As every operation, in every industry on which cost or wage payment standards are set, must include allowances, the importance of this method is evident. It is called Ratio-Delay Study (Morrow, paper presented at Annual Meeting of the A. S. M. E., Dec. 1940).

Ratio-delay study is recording, at random intervals, the status of a machine, that is, whether it is running or idle. If a sufficiently large number of observations are taken, to quote Tippett, "the percentage number of readings that record the machine as working will tend to equal the percentage time it is in that state."

Likewise, if random observations are taken of the operator's cycle of work, "the percentage of readings recording the operatives as performing a certain operation or group of operations is an estimate of the percentage time spent in those operations." If the readings "are randomly distributed over a sufficiently long time, this relationship holds whether the machine stoppages or operations of the operatives are short or long, many or few, regular or irregular."

The method is to make each observation at the instant the observer reaches a given point—for instance, when he is directly alongside the

Code No.	Reasons for Downtime
1	Personal time
2	Jams, in or about mandrel
3	Gage or inspect work
4	Change tote boxes
5	Mechanic adjusts machine
6	Automatic hopper not delivering
7	Mechanic adjusts machine—operator on another job
8	Wait for work
9	Clean machine
10	Change jobs
11	Get O.K. on quality of work from foreman or mechanic
12	Wait for mechanic to adjust
13	Pick out scrap or bad work from finished work tote box
14	Make out production report
15	Inability to keep up with machine
16	Clean chute
17	Miscellaneous

FIG. 37. Code of Reasons for Downtime—Eraser Holder Manufacture

BATTERY NO. 1

Mach. No.	Operation	Part No.	Brass	Part Name	Mach. Speed	No. Times Running	No. Times Down (by Code Nos.) 1	2	4	5	6	7	8	9	17	Grand Total
550	Stamp	117	Lo	R.T.	150	120	6	1		15	14	3				159
551	Stamp	182	Hi	R.T.		54	3	2	1	10	10					80
1991	Knurl	30	Hi	R.T.	138	165	5	1		1	27					199
525	Shear	174	Hi	R.T.	108x2	166	8	7		6	15					202
521	Knurl	30	Hi	R.T.	100	182	7	1			3					193
583	Knurl	78	Lo	R.T.		123	4				2			1		130
514	Knurl	30	Lo	R.T.	143	153	7	2		16	23	1				202
						963	40	14	1	48	94	4		1		1,165

BATTERY NO. 2

Mach. No.	Operation	Part No.	Brass	Part Name	Mach. Speed	No. Times Running	No. Times Down (by Code Nos.) 1	2	4	5	6	7	8	9	17	Grand Total
585	Knurl	174	Lo	R.T.	148	169	6			1	21			1		197
504	Knurl	817	Lo	R.T.	114 – 121	179	6	1			12			1		199
503	Knurl	174	Lo	R.T.	147	173	6				18					197
506	Knurl	59	Hi	R.T.	156	121	5	1			30		4			161
507	Knurl	30	Lo	R.T.	152	132	6	5			59			1		203
505	Knurl	78	Lo	R.T.	134	131	5	1			2					139
578	Shear	174	Hi	R.T.	127x2	139	6	6			39	2			4	196
						1,043	40	14		1	181	2	4	3	4	1,292
Totals of Batteries No. 1 and No. 2...						2,006	80	28		49	275	6	4	4	4	2,457

FIG. 38. Summary Sheet of Downtime of Automatic Hopper Chute-Fed Machines

workplace—noting whether the operator is working, or if not, cause of the delay. This practice gives a definite recording instant.

Operators, if told the purpose of the study, go about their duties as usual. As no stop-watch is used, one of the operators' objections to time studies is eliminated.

Tippett, in describing the accuracy of the results obtained in English textile mills, says, "Unless exceptional precautions are taken, the total error is not likely to be reduced much below about 2%, except when the percentage measured is very high or very low (between 0% and 5% and between 95% and 100%), or comparisons are being made under conditions in which systematic errors are constant."

Ratio-delay studies were made at the Eagle Pencil Company on two groups of machines, one automatic hopper chute-fed, the other hand-fed, on operations such as trim, knurl, and shear small metal parts, used as pencil eraser holders. The delay allowances to determine "down-time" were calculated as a check on existing allowances and to evaluate the new method.

The code of reasons for downtime, summary sheets for automatic hopper chute-fed machines and hand-fed machines, and the findings of the study are given in Figs. 37 to 40.

Mach. No.	Operation	Part No.	Part Name	Mach. Speed	No. Times Running	No. Times Down (by Code Nos)		Totals
						1	2 to 17	
579	Trim (comb.)	174	(Shell rubber tip 4 out)	82	190	3	8	201
580	2nd Trim	207	Bushing	85	94	1	1	96
581	1st Trim	8	Cap	96	63	1	7	71
574	1st Trim	207	Bushing		157	1	11	169
576	1st Trim	117	Rubber tip	105	160	1	6	167
568	2nd Trim	117	Rubber tip	103	196	3	4	203
517	2nd Trim	75-21-5	Cap		34	1	2	37
508	2nd Trim	249	End sleeve	104	35	1	8	44
	Totals				739	9	39	787
523	Knurl	2570	Caps		47	1	4	52
512	Knurl	182	Rubber tips	108	28	3	1	32
511	Knurl	117	Rubber tips	114	125	3	2	130
518	Knurl	1374	Protectors		22	2	4	28
524	Knurl	576	Caps	128	86	2	1	89
	Totals				308	11	12	331
549	Stamping	112	Cap	80	56	1	9	66
548	Flare	145	Rubber tip	112	45	4	4	53
519	Knurl & flare	207	Case bushing	66	74	2	3	79
1375	Slot & head	1374	Protector		54	1	10	65
211	Slot	174	Protector	67	41	—	5	46
545	Notching	207	Rubber tip	112	14	—	—	14
543	Imprint	145	Rubber tip	98	23	1	2	26
516	Knurl & shear	139	Rubber tip	93	97	4	9	110
544	Notch & flare	202	Bushing	49	69	2	—	71
	Total miscellaneous machines..............				473	15	42	530
	Total all machines.......................				1,710	38	101	1,849

FIG. 39. Summary Sheet of Downtime of Hand-Fed Machines

Item	Automatic Hopper Chute-Fed Machines, Battery No. 2			Hand-Fed Machines		
	Observations	Percentages		Observations	Percentages	
Total	2,457	100.00	—	1,849	100.00	—
Running	2,006	81.65	100.00	1,710	92.48	100.00
Not running, down	371	15.10	18.5	101	5.46	5.9
Personal	80	3.25	—	38	2.06	—
Downtime—8-hr. day		72.40 min.			26.21 min.	

Total for Automatic Hopper Chute-Fed and Hand-Fed Machines

Item	Observations	Percentage	
Total	4,306	100.00	—
Running	3,716		100 0
Personal	118	2.74	3.2
Personal time—8-hr. day		13.15 min.	

Fig. 40. Summary of Downtime Covering All Observations

Fig. 41 shows the comparison of downtime values based on running times, as compared with values obtained by stop-watch studies used as standards. A standard allowance of 3% is made for personal time. Ratio-delay study indicates that 3.2% is actually used. Note agreement in Fig. 41 between standard values and those obtained by ratio-delay study. Standard values were based on data obtained from many stop-watch studies taken over a period of 4 years.

Equipment	Values	
	Ratio Delay Study	Standard (time study)
Trimming Machines	5.9%	5.0%
Knurling "		5.0
Stamping "		6.0
Automatic Hopper-Fed Seven-Machine Battery	18.5	17.0

Fig. 41. Comparison Between Ratio-Delay and Time Study Downtime Values

At the J. E. Ogden Co. four jobs were selected for study, as follows:

A: Attaching two U-shaped wires to a small metal cup on a machine consisting of pliers operated by foot treadles. Usually there were three operators, but the number varied.

B: A packaging job. Either four or five operators were on this job during observation period.

C: A foot-press shear and packaging job. Either two or three operators were at work during observation period.

D: A punch-press job, using medium Bliss inclinable presses. An average of four presses were on the work during observation period.

Item	Job A		Job B		Job C		Job D	
	No. of Readings	%	No. of Readings	%	No. of Readings	%	No. of Readings	%
Total readings	372	100.0	649	100.0	38[illegible]	100.0	608	100.0
Allowable delays	29	7.8	93	14.3	78	20.1	61	10.0
Unnecessary delays	26	7.0	70	10.8	105	27.1	24	4.0
Productive or operating readings	317	85.2	486	74.9	204	52.8	523	86.0

FIG. 42. Ratio-Delay Study Data on Four Kinds of Jobs

Item	Allowable Delay				Unnecessary Delay				Running Time			
Job	A	B	C	D	A	B	C	D	A	B	C	D
Ratio Delay	7.8%	14.3%	20.1%	10 0%	7.0%	10.8%	27.1%	4.0%	85.2%	74.9%	52.8%	86.0%
Prod. Study	10.0	16.0	20.0	11.3	8.0	13.6	22.9	.5	82.0	70.4	57.1	88.2
Difference	−2.2	−1.7	+ .1	−1.3	−1.0	−2.8	+4.2	+3.5	+3.2	+4.5	−4.3	−2.2

Above delay percentages are based on percentage of total time, rather than percentage of productive time, and are useful only in the above comparison.

FIG. 43. Comparison of Ratio-Delay Study Data from Fig. 41 with Production Study Data on the Same Jobs

The method of collecting data was to make observations at random intervals during each day, over 18 working days. For purposes of comparison, on each of jobs A, B, and C, a full day's production study was made to determine delay allowances. On job D, a downtime recorder was used to record each stop and its duration. This latter record was made for 15 days, on one of the blanking presses. Fig. 42 shows the totals of the various readings in number and percentage distribution. Fig. 43 compares the percentages of allowable delays, unnecessary delays, and productive operation readings in the ratio-delay study with those set by production studies, and shows the close agreement between results under the two methods.

Conclusions Regarding Ratio-Delay Studies.—The following conclusions may be drawn from the results of ratio-delay studies which have been carried on:

1. Only homogeneous groups should be combined—such as delays on similar operations performed on similar kinds of machines, or delays of operators on work of a similar nature.
2. A large number of observations is recommended. Studies are best adapted to large groups of machines or operators. When the number of observations on the job was about 500, a fairly reliable result was obtained. Over 3,000 observations gave very accurate results.
3. Results from a few hundred observations may be used, if the frequency distribution conforms to the binomial law.
4. Accuracy of results may be determined in any case.
5. As percentage of delay time increases, more observations are necessary for a given accuracy.
6. Data are more reliable if the observations are taken over a long period of time.
7. Observations must be taken at random intervals and distributed over all hours of the day and week.
8. Intervals between samples must be sufficient to give independent readings.
9. Ratio-delay study provides an opportunity to observe and evaluate operations of a department as a whole.
10. Observer's work may be interrupted at any time without affecting the study. Taking studies is not tedious for observer.
11. There has been no objection to ratio-delay studies by operators, because no stop-watch is used and operators are not subjected to long periods of close observation.
12. Cost of ratio-delay studies is about one-third that of production studies.

WRITE-UP OF STUDY: STANDARD SEQUENCE.—The write-up of every job studied should be a formal and precise report including a permanent record of all conditions under which the study was made, and a detailed description as to the one best way developed. Fig. 10 is an example of a formal task report. At the top, identifying and filing data are entered and the results obtained are stated, as these are most frequently referred to items. The report is divided into two main parts: (1) analysis, and (2) synthesis.

Analysis includes a detailed description of the method of performing the operation and all details necessary to enable the job to be set up in standard fashion at any future time. As part of the analysis, elementary operations are listed in the sequence in which they are performed by all subjects involved in the study. Each detail may be given a symbol

at the left, and at the right is shown selected time as determined by the study. The description of detail operations should be so full and complete that no doubt could arise as to the exact series of motions used.

Synthesis consists of putting together the detail operations to form one complete cycle. Explanation of the method of putting the details together is given under this head. If any mathematical formula is used, it is stated, by means of symbols in algebraic form. Time for unavoidable delays may be included and allowances for rest and delay made here also.

Calculations of task and perhaps piece price follow. Space is provided at the bottom of the sheet for the signature of the checker of the study and for approval of the executive who makes the study effective. A special blank form for write-up is not a necessity, but is a convenience and saves time when many studies are to be made. When a prepared form is not used, the write-up is made in the same manner on blank paper and follows a sequential plan.

THE INSTRUCTION CARD.—The instruction card is an important part of the write-up. Its function is to convey to the worker complete information required for doing the standardized task. It should tell him:

1. What equipment, tools, fixtures, and gages to use, and what drawings are required if any. If the same set of tools is used on several different jobs, the list may be made out on a separate card so that it can be used with the instruction card for any job.
2. Feeds and speeds to be used, if they are under the worker's control.
3. What to do and how to do it. It should list elementary operations in their final sequence and in detail, should give sketches of set-up, if necessary for clearness, give standardized time allowed for each elementary operation, and for the whole operation so that worker may know in advance all that is expected.
4. Pay, and incentive if any, allowed for performance of task.

In general, information on the instruction card will follow closely that on the observation sheet covering the final or perfected stage of study, with addition of such other data on equipment and method as the production worker may require. It forms a complete and permanent record of the task as standardized. With the tools called for, and the best motions described, a properly qualified worker, after a reasonable amount of training and practice, should be able to perform the task in the time set.

Standard Data Method

ORIGIN OF THE STANDARD DATA METHOD.—The standard data method can be traced back to studies of Taylor and Merrick It was planned to compile a "dictionary" of fundamental elements necessary to perform work, with times that skilled operators should take for these elements.

Taylor's view of this feature of time study was:

No system of time study can be looked upon as a success unless it enables the time observer, after a reasonable amount of study, to predict with accuracy how long it should take a good man to do almost any job

in the particular trade, or branch of a trade, to which the time student has been devoting himself.

It is true that hardly any two jobs in a given trade are exactly the same, and if a time study student were to follow the old method of studying and recording the whole time to do the various jobs which came under his observation, without dividing them into their elements, he would make comparatively small progress in a lifetime, and at best would become a skilful guesser. It is, however, equally true that all of the work done in a given trade can be divided into a comparatively small number of elements or units, and with proper implements and methods it is comparatively easy for a skilled observer to determine the time required by a good man to do any one of these elementary units. (Shop Management.)

This plan was carried out by Merrick, inasmuch as he took many studies of machine shop operations and compiled tables of minimum selected times, readily converted into standard times (Merrick, Time Study Data—General Description, Index and Data, Blueprints 1 to 692, Watertown Arsenal, U.S.A. See Fig. 44).

Time study procedure in many factories had been to take studies as required and determine a standard from a single study on one operator. When this plan is followed, any variation from normal in the operator's skill, effort, conditions, or consistency, which occurs when the study is taken, and is not correctly allowed for in "leveling," or "grading," results in an incorrect time standard.

A better practice is to use the indirect or standard data method. Standard times for elements compiled from many studies are the basis for the standard. By determining such standard elemental times from many studies on different operators, variations in work conditions and errors in judging how the operator worked are averaged out. The standard elements, properly combined, will give a true standard, when conditions are standardized within practical limits before the job is begun.

ADVANTAGES OF THE METHOD.—Carroll (Time Study for Cost Control) lists the advantages of using the standard data method:

1. The actual cost of the standard is considerably lower.
2. The standard can be set more quickly and accurately.
3. Standards are consistent with each other.
4. The standard can readily be explained to the employee.
5. Standards are determined before the jobs start.
6. Jobbing work can be measured at a reasonable cost.
7. Long operations can be subdivided for daily computation.
8. When necessary, a standard can be reproduced.

DISADVANTAGES OF THE METHOD.—The disadvantages are the time interval between the beginning of time study work and the actual setting of the standards required for preparation of the data; and the possibility of errors and the difficulty of compiling data and defining variable dimensions unless considerable engineering skill is used.

PRELIMINARY STUDIES: HIGH-LOW LIMITS.—Operations which are similar should be grouped for study. For instance, in a department where operators are drilling, milling, and bench filing, the studies would be divided into three groups. A general plan should be decided upon which will account for all variations. Spot studies would be taken in each group, covering the ranges in weight, size, shape, or other significant variables of the work, and all essential data should be

WATERTOWN ARSENAL, U.S.A

OBSERVATIONS OF WORK ON 6 FT. RADIAL DRILL PRESS — 349

TIME FOR SPOTTING & DRILLING-TO LAYOUT LINES

OBSERVER'S NAME A. F. CARY **MACHINE** 4 DR-DM 3-6 FT. WESTERN RADIAL
WORKER'S NAME N. E. PARNELL **DATE** 5-17- **PIECE**
WEIGHT ____ **LBS.**

SPOT & DRILL – FIRST HOLE		MIN. TIME IN MIN. RADICAL ARM TIGHTENED	MIN. TIME IN MIN. RADICAL ARM NOT TIGHTENED
GET DRILL		0.06	0.06
PUT DRILL IN SOCKET		0.09	0.09
PUT SOCKET IN SPINDLE		0.09	0.09
PUNCH CENTER HOLE LARGER		0.06	0.06
START MACHINE		0.12	0.12
SET DRILL TO CENTER PUNCH HOLE		0.21	0.21
TIGHTEN RADIAL ARM		0.12	
SPINDLE DOWN-FEED IN –TWICE	.03	0.06	0.06
SPOT –TWICE	—	—	—
FEED OUT-SPINDLE UP –TWICE	.06	0.12	0.12
DRAW CENTER –TWICE	.21	0.42	0.42
SPINDLE DOWN-FEED IN		0.03	0.03
DRILL		—	—
FEED OUT – SPINDLE UP		0.09	0.09
STOP MACHINE		0.09	0.09
LOOSEN RADIAL ARM		0.09	
GET DRIFT		0.12	0.12
DRIFT SOCKET OUT OF SPINDLE		0.09	0.09
DRIFT DRILL OUT OF SOCKET		0.09	0.09
REMOVE DRILL & SOCKET		0.06	0.06
TOTAL (0.0335 HRS.)		2.01	
TOTAL (0.0300 HRS.)			1.80
EACH ADDITIONAL HOLE			
PUNCH CENTER HOLE LARGER		0.06	0.06
SET DRILL TO CENTER PUNCH HOLE		0.21	0.21
TIGHTEN RADIAL ARM		0.12	
SPINDLE DOWN-FEED IN –TWICE	.03	0.06	0.06
SPOT –TWICE	—	—	—
FEED OUT-SPINDLE UP –TWICE	.06	0.12	0.12
DRAW CENTER –TWICE	.21	0.42	0.42
SPINDLE DOWN-FEED IN		0.03	0.03
DRILL		—	—
FEED OUT – SPINDLE UP.		0.09	0.09
LOOSEN RADIAL ARM		0.09	
TOTAL (0.0200 HRS.)		1.20	
TOTAL (0.0165 HRS.)			0.99

NOTE – IN FIGURING TIME FOR DRILLING, ALLOW EXTRA LENGTH OF RUN EQUAL TO 1/3 DIAMETER OF HOLE, FOR SPOTTING & EXTRA LENGTH OF RUN.

1"

MADE	5-31-	REVISED					D.V. Merrick	Y	8 C	2

FIG. 44. Observation Sheet with Standard Minimum Times—Merrick

recorded. Care should be taken to obtain studies on nigh and low limits. For example, where the weight of the part is an important factor, both heaviest and lightest parts should be studied. The data will be good for further use only between these limits.

MASTER LIST OF ELEMENTS.—From the preliminary studies a master list is made up of those elements occurring in the spot studies. The master list should be comprehensive, including all elements usual to the operations studied, and each element should be well defined. In continuing the studies, observers must adhere to elements already defined and listed, so that comparative data will be recorded.

COMPARISON SHEET.—On a large comparison sheet, or master table of detail time studies as shown in Fig. 45 (Stegemerten, Am. Mach. vol. 82), the master list of elements is recorded on the left-hand side of the sheet. In each succeeding column, data from each study are noted, opposite the corresponding elements. Across the top of the sheet is given important identifying information, such as characteristics of part, name of operator, leveling or grading of operator, machine, speed, tools, etc. It is better to include all information in every detail, than later to discover that important facts have not been recorded. Study of this comparison sheet will bring to light the fixed and variable elements. Some elements will be found to have a nearly constant value regardless of the job; others will vary, in which case the reason for the variation should be made a subject of further study.

Observed times are entered on the comparison sheet after they have been graded or leveled and usually after allowances for personal fatigue, delays, and variations have been added. The data are used in this case for formula construction purposes. Time study men find out which operations occur frequently and what additional studies must be made.

SET-UP STANDARDS.—The method of determining set-up standards is similar to that just described for operation standards. Usually it is better to have set-up standards separate from operation standards, although, in some cases, set-up time may be prorated over number of pieces in the lot, and the operation standard will then include set-up. The latter method may be more convenient for shop records, but it will not be accurate unless the size of lots is uniform, or set-up time is very short in proportion to operation time.

TREATMENT OF VARIABLES.—Fundamental causes of time variation in each element should be analyzed, one of the following methods being used (Carroll, S. A. M. Jour., vol. 4):

Method	
1. Curves at once apparent 2. Tables	Simple 1 or 2 variables
3. Equations 4. Alignment chart	Intermediate
5. Family of curves 6. Multi-variable chart	Complicated 3 or more variables

COMPARATIVE COSTS.—While the indirect or standard data method is slower at beginning, because no standards are set until many time studies have been taken and computations are made, yet the cost of time study work by this method is far less than by the direct method. Carroll (S. A. M. Jour., vol. 4) takes a hypothetical case, requiring 2,500 standards, and shows comparative time and cost for each method.

SHEET NO. 1
OF 1 SHEETS

MASTER TABLE OF DETAIL TIME STUDIES

FORMULA F-13 #7
DATE MAY 1, 19—
PART ENCLOSING CABINETS
OPERATION LAYOUT PANEL FOR DRILLING & ASSEMBLE PANEL TO BOX
PERFORMED ON BENCH
COMPILED BY J. A. Smith

JOB CHARACTERISTICS	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
STUDY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
OPERATOR	Hiler	Hiler	Hiler	Gatheral	Gatheral	Hiler	Hiler	Hiler	Gatheral	Gatheral	Hiler	Marion	
SKILL EFFORT	G E	G E	G E	G A	A A	G G	G E	G G	G G	G G	G E	G G	
Assemble	✓	✓	✓	✓	✓	✓	✓					✓	
Layout								✓	✓	✓	✓		
Panel Area	50	168	108	778	280	1275	296	296	575	910	1275	1030	
Drawing No.	610449	315866	435819	423517	454[illegible]	371827	371902	371902	401362	602278	371827	612930	
How Mounted	Mount stud	Mounting brackets	Mount on stud		Mount on stud	Mounting brackets	Mounting brackets					Mounting brackets	
				Cline									

SYMBOL	OPERATION DESCRIPTION	TIME ALLOWED (HOURS)	REFERENCE		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
A	Put in one mounting stud complete	Eq. 1		V	0150		0135		0198								
B	Put on one name plate complete	Eq. 2 or 3		V	0316	0378	0351		0419							1048	
C	Prepare electric hand drill	0121	S-1	C	0121	0127	0102		0166							0048	
D	Place one rubber washer on stud	0026	S-3	M	0030		0026										
E	Place panel in box	Eq. 7		V	0120	0121	0095	0086	0060	0061	0072		0014	0148	0095	0043	
F	Bolt panel to mounting stud per stud	0080	Comp E.A.	C	0110		0065		0065								
G	Put on one coverlock	0550	Comp E.A.	C	0519		0534										
H	Remove box	0049	S-7	C			0044		0045	0061	0049	0084	0035	0105	0042		
I	Chalk areas or mark holes for filing	0116	S-11	C		0120						0065	0099	0204	0116		
J	Put in one bolt with wrench	0108	S2 & 4	C		0108		0108								0110	
K	Remove panel from box	Eq. 8		V		0035		0029			0044				0058		
L	Get box	0075	S-3	C			0075	0062	0039	0091	0065	0121	0071	0222	0116		
M	Get panel from or remove to stock pile	Eq. 9		V			0081		0123	0110	0173	0056	0078	0107		0122	
N	Cut off one brass bolt on back of panel	0015	S-3	M			0015		0017								
O	Layout all name plate holes for drilling	Eq. 4		V											0355		
P	Fit Panel into position	Eq. 10		V				0166	0070	0031	0084		0136			0158	
Q	Set box on floor	0100	S-6	C					0094	0100	0083			0084			
R	Tie or untie tags	0036	Comp E.A.	C										0053			
S	Cut 1 hole in side of box, finish file & fit cover plate comp.	2907	S 7	M							2907						
T	Layout & saw one mounting support complete	1249	S 7	M							1249						
U	Layout side hole, center punch around, layout & piece [illegible]	1360	S-8	M								1360					
V	Layout one hole for drilling	0028	S-10	C								0013	0030	0028	0026		
W	Center punch one hole	0039	S-10	C								0015		0039	0061		
X	Chalk mark around one punch point	0008	S-11	C								0010			0008		
Y	Layout & mark one hole in side of box	0298	S-11	M											0298		
Z	Put in switch handle complete	0827	S-6	M						0827							
A₁	Put on 1 name plate after holes are drilled	Eq. 5 or 6		V						0132	0232						
B₁	File ream one hole in panel	0144	S-4	M				0144									

No panels fitted properly so mounting time is disregarded on this study

These operations were selected from a study on mounting a Cline controller to eke out available data.

FIG. 45. Master Table to Which Data from Individual Studies Are Transferred.

Direct Method:

Total number of standards required	2,500
Average number standards set per week per man	25
Number of time study men	3
Approximate weeks required to set 2,500 standards	33
Weekly salary of time study man	$50
Total approximate cost to set standards (3 × 50 × 33)	$5,000
Cost of each standard	$2

Indirect Method:

Total number of standards required	2,500
Weeks necessary to assemble data	4
Average number of standards per week, per man after data are assembled	125
Number of time study men	3
Approximate weeks required to set 2,500 standards after data are assembled	7
Total number of weeks to assemble and set standards	11
Total cost to assemble and set standards (3 × 50 × 11)	$1,650
Cost of each standard	$ .66

Thus cost per standard by the standard data or indirect method is only about one-third of the cost by the direct method. Frequently coverage of work by standards is 40% under the direct method, as compared with 95% under the standard data method.

STANDARD TIME DATA: PARTS HANDLING.—Specimen standard data times for a part handled by hand are given in the accompanying tabulation and diagrams, Figs. 46, 47, 48 and 49 (Am. Mach., vol. 82).

PART.
Part handling by hand.

OPERATION:
Pick up part and put on table, in vise or in jig or fixture; tighten vise, or fixture; release vise, jig or fixture; turn part over on table or in vise; remove from table, vise, jig or fixture and lay aside.

DESCRIPTION OF OPERATION (Time from Curves)

Description	
Pick up part and put in jig or fixture, or remove from jig or fixture and lay aside carefully	
Pick up part and put on table or in vise, or remove from table or vise and lay aside carefully	(Data
Remove part from jig or fixture and toss aside	given
Remove part from table or vise and toss aside	on
Release vise	curves)
Turn part over on table	
Tighten vise	
Turn part over in vise	

DESCRIPTION OF OPERATION ELEMENT

Element	Allowed Time Std. Hours
Open and close cover of jig or fixture when hinged	.0008
Close cover of jig or fixture when hinged	.0003
Open cover of jig or fixture when hinged	.0005
Put on and remove cover of jig or fixture when not hinged	.0029
Put on cover of jig or fixture when not hinged	.0020
Remove cover of jig or fixture when not hinged	.0009
Tighten and release wing nut	.0012
Tighten and release thumb screw by hand	.0013
Tighten thumb screw by hand	.0008
Release thumb screw by hand	.0005
Tighten and release one short locating screw by hand	.0018
Tighten one short locating screw by hand	.0010

FIG. 46. Allowed Time for Parts Handling

Description of Operation Element	Allowed Time Std. Hours
Release one short locating screw by hand	.0008
Tighten and release two short locating screws by hand	.0023
Tighten two short locating screws by hand	.0013
Release two short locating screws by hand	.0010
Tighten and release one long locating screw by hand	.0037
Tighten one long locating screw by hand	.0021
Release one long locating screw by hand	.0016
Tighten and release two long locating screws by hand	.0047
Tighten two long locating screws by hand	.0027
Release two long locating screws by hand	.0020
Tighten and release locating screws with a wrench	.0053
Tighten locating screw with a wrench	.0035
Release locating screw with a wrench	.0018
Tighten and release hexagon or square nut with an open-end wrench	.0034
Tighten hexagon or square nut with an open-end wrench	.0018
Release hexagon or square nut with an open-end wrench	.0016
Insert and remove bushing from jig or fixture	.0010
Insert or remove bushing from jig or fixture	.0005
Insert and remove locating pin from jig or fixture	.0046
Insert locating pin in jig or fixture	.0018
Remove locating pin from jig or fixture	.0028
Blow cuttings from small or medium jig or fixture with an air hose	.0014
Blow cuttings from large jig or fixture with an air hose	.0020
Clean small jig or fixture with brush	.0020
Clean medium jig or fixture with brush	.0028
Clean large jig or fixture with brush	.0035
Clean very large jig or fixture with brush	.0049
Clean small jig or fixture by turning over	.0014
Clean medium jig or fixture by turning over	.0022
Clean large jig or fixture by turning over	.0029
Clean very large jig or fixture by turning over	.0043
Tighten and release a machine vise, hit part with a rawhide mallet	.0043
Tighten vise on machine with rawhide mallet and hit part	.0031
Release vise on machine with rawhide mallet	.0012
Clean vise	.0020
Set and tighten, release and move clamp already in place	.0059
Set and tighten clamp already in place	.0035
Release and move aside clamp in place	.0024
Place, set and tighten, release and remove clamp not in place	.0116
Place, set and tighten clamp complete	.0076
Release and move aside complete clamp	.0040
Set jack screw	.0021
Make jib crane lift from machine to turn part and return	.0250
Make jib crane lift from floor to lathe and return	.0500
Make jib crane lift from floor to machine table and return	.0622
Make jib crane lift from floor to jig or fixture and return	.0779

Note: The term "allowed time" represents the time required by any worker to perform a given unit of work, using average skill, showing average effort, under average conditions, with average consistency, allowing for fatigue, personal needs, and unavoidable delays. *It is the time within which the worker is expected to perform that work.* All times are given in decimal hours. Accurate conversions to minutes and seconds can be made by means of the following formulas: decimal hours $\times$ 60 = decimal minutes; decimal hours $\times$ 3600 = decimal seconds. The data given represent standards developed for use at East Pittsburgh Works of Westinghouse Electric & Manufacturing Company for conditions of work existing in that plant. Each allowance should be checked in the light of local conditions before being applied in any other plant.

Fig. 46. (*Continued*)

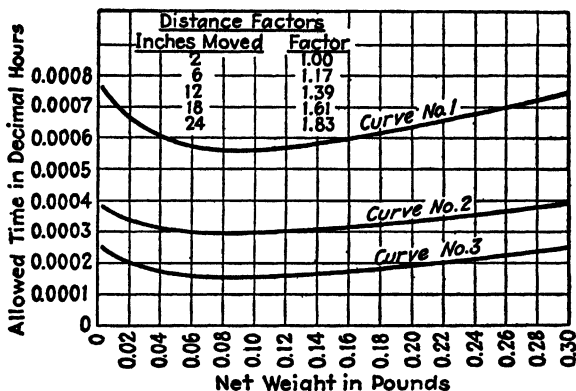



FIG. 47. Time Allowance Curves for Handling Parts Where Only Finger, Wrist, and Arm Movements Are Involved

Curve 1 shows allowance for time to pick up a part and place it in a jig or fixture. Curve 2 is read both for time allowed to pick up a part and place it on a table or in a vise, and for time allowed to remove the part from the jig or fixture and lay it aside. Time allowed for laying a part aside is read from curve 3. Distance factor is to be applied in all cases.

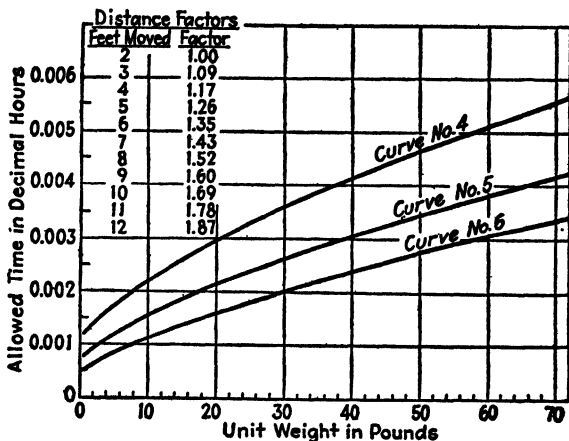



FIG. 48. Curves Giving Allowances for Handling Parts Where Finger, Wrist, Arm, and Body Are Used

Time allowed to pick up a part and place it in a jig or fixture is read from curve 4. Curve 5 shows both time allowed to pick up a part and place it on a table or a vise, and time allowed to remove a part from a jig or a fixture and lay it aside. Curve 6 is read for time allowed to lay a part aside. Each reading must be multiplied by the proper distance factor.

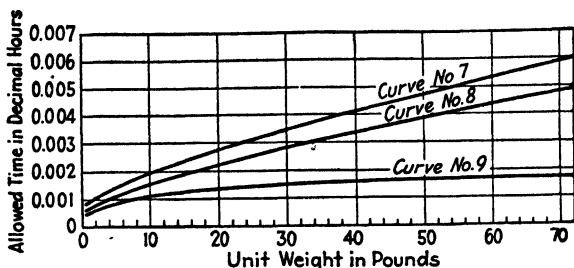



FIG. 49. Time Allowance Curves for Turning a Part Over in a Vise and Tightening and Releasing Vise

Curve 7 is read for time allowed to turn a part over in a vise. Both time allowed for turning a part over on a table and that allowed for tightening a vise is shown by curve 8. Time allowed to release a vise is read from curve 9. These operations are affected only by the weight of the piece.

The preceding data have been compiled with the object of standardizing part handling times in all departments of a factory, thus making the information of general value. They were compiled from studies on actual production jobs in several shop sections, some studies being taken with ideal set-ups to show how various factors affect the time. Constants were selected from a wide range of formulas and time studies.

The time values obtained from these data are to be used in formulas or standard data developed for a wide range of shop operations, as too much time would be involved in establishing "each piece" values directly from this information.

Parts always should be placed so that they can be handled to the greatest advantage, without interfering with the movements of the operator. In some cases skids, skid boxes, trucks and other materials handling units may facilitate the handling operations. They always should be introduced where advantageous. (Westinghouse Electric & Mfg. Co.)

No binding rule was made to govern the weight that a man shall lift. While 75 lb. has been chosen arbitrarily as the maximum, this load should be handled only when the operator has been instructed in the correct method of lifting, is physically fit, and the operation is not of frequent recurrence. When lifting is done near acids, hot metals, hot liquids, oily floors, or running machinery, the maximum load should be decreased.

Values were established for electric jib-crane lifts. Air hoists are used only where there is a fire hazard. Speed at which electric hoists operate under load has been found to vary from 36 ft. per min. for a 1/4 ton hoist to 15 ft. per min. for a 1-ton hoist. A straight-up lift of 5 ft., in most cases, will constitute a maximum distance of lift and this is the basis for the jib-crane lift time values shown in the tabulation.

Fig. 47 gives three curves relating time and weight in handling parts which involve finger, wrist, and arm motions. Fig. 48 gives three curves applying to handling parts where movements of finger, wrist, arm, and body are required. The curves of Fig. 49 apply to turning a part over and tightening and releasing in a vise.

Factors for distance moved, curves 1 to 6 in Figs. 47 and 48, were found by moving parts of approximately similar shape, and increasing weights and volumes, through various distances. Parts of approximately the same weight, and varying volumes and areas, were moved definite distances, showing that time was not materially affected, when distance moved was constant. This procedure was applied to castings, forged parts, and short bars, but not to bar stock where length is great in proportion to cross-sectional area. Handling times for jigs or fixtures are the same as any other parts of like weight.

Values have been established for long and short locating screws, a short locating screw being considered as one which has to be tightened or loosened 1/4 in. or less.

While in some cases more than one part can be handled at a time, no allowance has been made for this situation in the handling data. Such allowance is made by the individual applying these data.

Curves for such handling time allowances are given in Figs. 47, 48, and 49.

The operations are divided into two classes: first, those which are affected by the distance moved and second, those which are not. Curves 1, 2, and 3 are for small parts up to .30 lb. where finger, wrist and arm movements only are involved, while curves 4, 5, and 6 are for parts where finger, wrist, arm, and body movements are involved. These curves are based on minimum distances in both cases and the values obtained from the curves must be multiplied by the distance factor given with each set of curves. Curves 7, 8, and 9 are those operations which are not affected by the distance moved.

Curves which are affected by distance follow the same general trend. Handling curves involving finger, wrist, and arm movements show a slight decrease until an ideal size part is reached, then a gradual increase as weight is increased.

It requires the same time to place parts aside carefully in a pan as it does to pick them up.

Curves for turning pieces over on a table, or in a vise, and for tightening and releasing vise, follow the same general trend. Since the observers were not able to get information on the handling of very small parts for this operation, only one set of curves is given.

Complex Time Studies

AUTOMATIC MACHINE OPERATION.—When power feed automatic machines are used, and the operator handles two or more machines, computation of standard times becomes somewhat complicated. The operator may place a part or piece in the machine, clamp it in place, start the automatic feed and, often, have nothing further to do on that machine until the cut or machine run is finished, and the piece is ready to be removed. An example is the power-feed milling machine, for which a typical operation cycle is: place piece in machine fixture, tap piece, clamp in place, move table, throw lever to start automatic feed, and—when machine "kicks off" at end of the cut—loosen and remove piece from the machine (Morrow).

However, on automatic screw machine operations, incidental work such as inspection and minor tool adjustments may have to be done

during the cutting time. This fact should be taken into account in making machine assignments.

In machines of the kinds mentioned, while cutting or machine time is taken from a time study, this time should be checked with calculations based on approved cutting feeds and speeds. Usually a 5% allowance is added to computed machine time for variations. The per cent allowance will depend upon kind and condition of machine and accuracy of its adjustment.

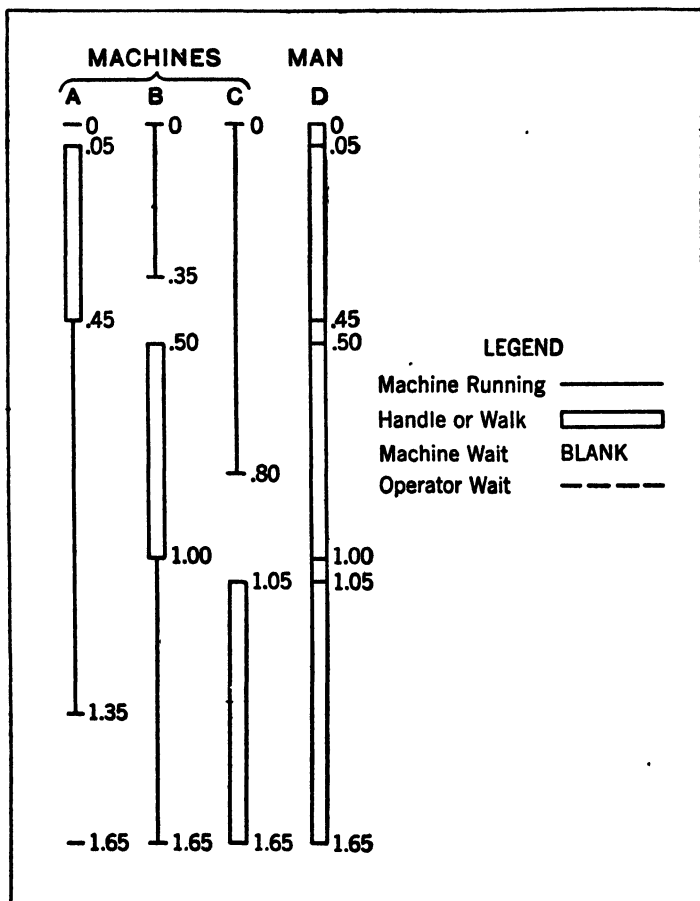



FIG. 50. Man-Machine Chart for Automatic Machine Cycle

SIMPLEST AUTOMATIC MACHINE CYCLE.—Charts, such as shown in Fig. 50, with time indicated on the vertical scales, are used to show machine running, operator handling, walking, interference, and man-waiting times. A, B, and C are the charts for three machines, while D is a man chart. The figures are the indicated times. Charts may be constructed commencing with machines at any desired stage of operations. As shown in the illustration, the chart indicates the man as walking to A, having just started C, which is now running, while B is partly through its run. While the man is handling machine A, machine B stops at .35 min. and must wait until the operator finishes handling A and has walked to B. At this point, interference time is from .35 to .45, or .10 min. If the operator is assigned too many machines, interference time becomes excessive and cost increase becomes uneconomic. Man chart D shows the operator working or walking 100% of the time, so that computation of standard times can be based on the walking and handling times alone. Allowances for personal fatigue and delays are made as usual (Morrow).

EXAMPLE OF MAN-MACHINE ANALYSIS

Factor	Machine A	Machine B	Machine C
Machine time	.900 min.	1.000 min.	.800 min.
Handling time	.400 "	.500 "	.600 "
Walking time	.050 "	.050 "	.050 "
Handling and walking	.450 "	.550 "	.650 "
Personal, fatigue delay allowance of 15%	.068	.083	.098
Working cycle	.518	.633	.748

Preparation, or time for getting tote box of work and removing finished pieces, takes 2.00 min. per 100 pieces, to which an allowance of 20% is added. Preparation on each machine is $(2.00 + 20\%) \div 100 = .024$ per piece.

EXAMPLE OF PREPARATION ALLOWANCES IN MAN-MACHINE ANALYSIS

Factor	Machine A	Machine B	Machine C
Working cycle	.518	.633	.748
Preparation	.024	.024	.024
Standard time per piece in minutes	.542	.657	.772

The 15% allowance on handling time for personal needs, fatigue, and delays, will vary for different jobs and should be determined from studies.

OPERATOR WAITING FOR MACHINE.—The machine time may be so long that the machine will not have completed its run by the time the operator returns to the machine after handling the other

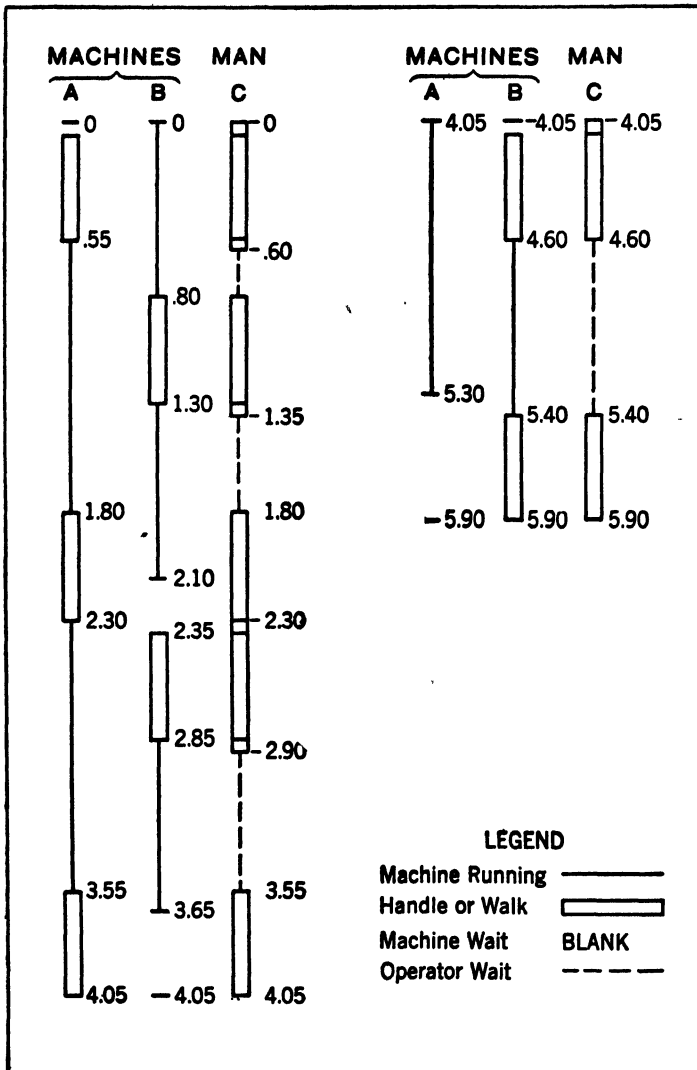



FIG. 51. Man-Machine Chart with Worker Waiting for Automatics to Finish Operations

machine or machines. This occurrence is shown in Fig. 51, chart of two-machine operation. After the man has finished handling machine A, he may walk to B, arriving there at .60 min., where he may wait until it is time to handle B. This wait is also shown on man chart C by the dotted line. Other man-waits occur throughout the cycle (Morrow).

The charts are extended for handling and running machine A three times, and for handling and running machine B four times. How far to carry out the chart is determined by cut-and-try methods.

The standard time for this cycle may be computed from the man-machine chart as follows:

Total handling and walking times .60 + .55 + 1.10 + .50 + .55 + .50 =	3.800
(shown by double lines chart C)	
Personal, fatigue, and delay allowance 15% =	.570
Man wait .20 + .45 + .65 + .80 (no added allowance) =	2.100
(shown by dotted lines on chart C)	
	6.470

Operator's handling or walking time:
Machine A (1.65 ÷ 3.80) or 43.5%
Machine B (2.15 ÷ 3.80) or 56.5%

Machine A produces 3 pieces or	
Standard time per piece (43.5% of 6.470) ÷ 3 =	.938
Machine B produces 4 pieces or	
Standard time per piece (56.5% of 6.470) ÷ 4 =	.914

In doing his work, the operator may have to bring tote boxes of work to his machine and remove finished parts. If this moving is merely a lift from floor to bench, taking .10 min., it may be done during any waiting time the operator has available and no allowance need be made in the computations. If the work must be obtained from a distance, taking a longer time, 2.00 min. for instance, allowance must be made, because both machines will have stopped running during the 2.00 min.

Machine waiting time or delay due to interference decreases productive machine time, eventually a point being reached where it is uneconomic to assign the operator more machines. It is important, therefore, to know the interference time. Graphic charts may be used in cases similar to the foregoing. Interruption sheets such as shown in Fig. 9 are sometimes used to record the observations of interruptions.

Another method with an experienced operator willing to give a good study on the machines, is to take a production or ratio delay study, recording machine running, "down" due to handling or "down" due to interference, together with other usual data. Interference is then obtained as a percentage of the handling time, or as a percentage of handling plus running times.

Interference may be determined from formulas developed to cover particular machines and operating conditions. Such formulas are recommended when their application and limitations are clearly defined.

INTERFERENCE FORMULAS.—Fry developed a formula for determining interference in congested telephone lines, when calls come through requiring use of the same trunk line.

Wright (Mech. Eng., vol. 58) gives a formula which he has adapted from Fry's formula, by converting it into terms of machine interference.

$$I = 50\left[\sqrt{(1 + X - N)^2 + 2N} - (1 + X - N)\right]$$

where I = Interference in percentage of attention time
X = Ratio of machine running time to attention time
N = Number of machine units assigned to one operator

The formula was checked with the analysis of more than 1,100 hr. of actual shop observations during which interference had been measured and recorded. These studies covered the operation of 8 entirely different kinds of machines and were therefore considered entirely general. It was found that the formula checked accurately with these actual shop studies for assignments of 6 or more machine units per operator, but did not agree when the assignment was less than 6.

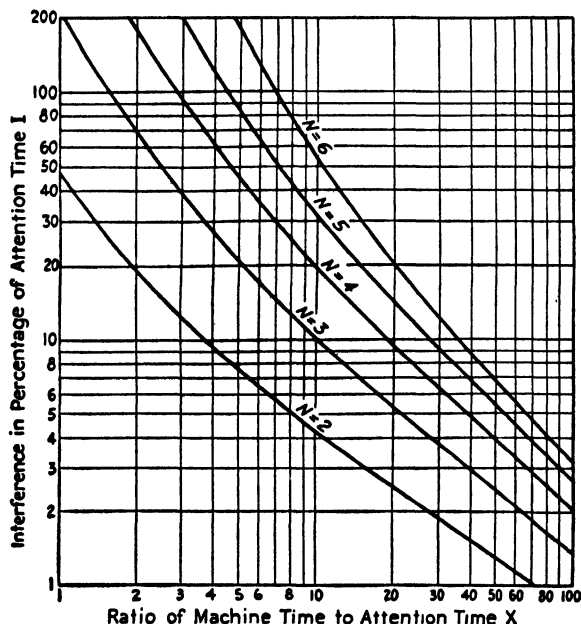



FIG. 52. Interference in Percentage of Attention Time—Operator Running Six or Less Machines

Wright recommends using a set of empiric curves (Fig. 52) when the number of machines is 6 or fewer than 6. These curves, for 1 to 5 machines, give interference values which are less than values obtained by solving the formula. For 6 machines, the chart and the formula give the same results, except at the upper and lower ends of the curve.

A further application of this interference study was to develop a formula for obtaining the economic number of machine units that should

be assigned to one operator. As the number of units assigned to an operator is increased, the labor cost is decreased, and the machine cost is increased. Economic assignment is reached when the cost is least, giving due consideration to both man and machine.

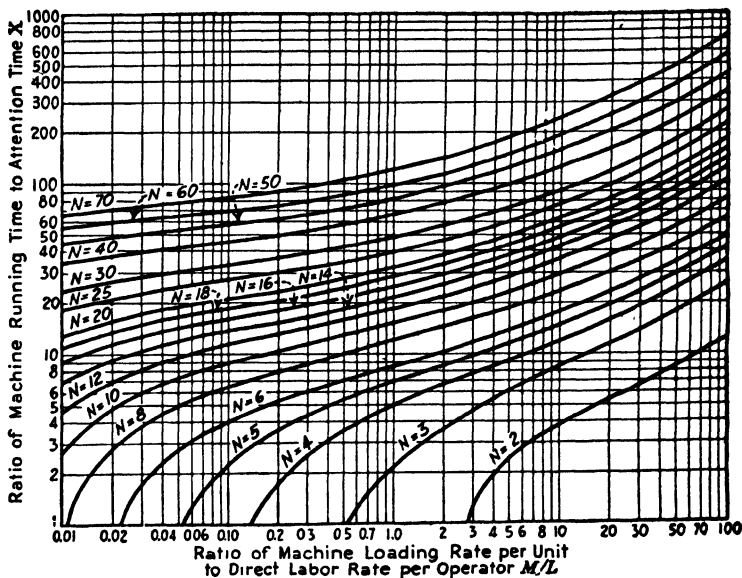



FIG. 53. Diagram for Determining the Number of Machines to Assign to an Operator

Fig. 53 is Wright's chart for determining this economic assignment. Application of chart and formula in a case where

Machine running time = 25 min. per lb.
Attention time = 1 min. per lb.
Cost chargeable to machine = $.125 per unit per hr. ($M$)
Direct labor cost = .50 per operator per hr. (L)

Referring to Fig. 53, lines $X = \frac{25}{1} = 25$ and $M/L = \frac{.125}{.50} = .25$ intersect at $N = 20$, the economic number of machine units to assign to the operator.

To arrive at the standard time, it is necessary to compute the interference—

$$I = 50 \left[\sqrt{(1 + 25 - 20)^2 + 2(20)} - (1 + 25 - 20) \right]$$
$$= 136\% \text{ of the attention time, or 1.36 min. per lb.}$$

Machine running time	25.00 min.
Attention time, including allowances	1.00 "
Interference	1.36 "
Total running, attention, interference time	27.36 "
Personal allowance 3%	.82 "
Standard time for 20 lb.	28.18 "
As one pound is produced on each of the 20 machines handled, then	
Standard time per 100 lb.	2.34 hr.
Earning rate	$ .50 per hr.
Piecework price per 100 lb.	$1.17

Wright's adaptation of Fry's formula was checked and compared with synthetic production studies by Hanser and Sandberg (New York University), as were other formulas, including the binomial application by Bernstein, Duval's formula, and several empiric formulas. Of these, Wright's adapted formula checked more closely with production studies, over the whole range of application, than any of the others. It is a simple formula to apply. For these reasons it is recommended as the most satisfactory yet evolved.

Work Assignment Illustrated

SILK LOOMS.—Alford (Mech. Eng., vol. 57) gives a formula and chart to determine a work assignment for silk looms. Into this problem enters the factor of loom interference. For this reason the method of computation is presented here.

In determining a work assignment for a weaver operating silk looms, two determinations are needed at the outset: the correct average amount of work which the weaver must do to produce 1,000 picks of the fabric on which a work assignment is to be set; and the standard allowance for free time.

For any job, after the average number of minutes per 1,000 picks produced and free time allowance have been determined, the work assignment of the weaver in thousands of picks is readily established for the work day whatever its length. The formula is:

$$\text{Work assignment in thousands of picks} = \frac{\left[\text{Minutes per work day}\right] \times \left[1 - \dfrac{\text{Per cent of free time allowance}}{100}\right]}{\text{Total minutes of work per 1,000 picks}}$$

Total minutes of work per 1,000 picks includes times for work while loom is stopped, while loom is running, walking to give attention, examining, and patrolling.

Example: Fabric, plain satin crepe.

Operation	Minutes
Work while loom is stopped	113.17
Work while loom is running	85.48
Walking to give attention	44.39
Examining	14.34
Patrolling	40.44
Total	297.82

The number of picks thrown is 249,000, and the minutes of total work per 1,000 picks thrown is $297.82/249 = 1.195$. Then the work assignment in thousands of picks per 8-hr. day, with 12½% free time allowance, is $480\ (1 - 12.5/100) \div 1.195 = 351+$. Therefore, the work assignment is 351,000 picks per 8-hr. day.

The piece rate for the job is readily set to give weekly earnings which are "equitable and agreeable for the work performed and the effort expended." To continue the example, assume that this amount is $27 for a 5-day week of 40 hr. Hence the piece rate $= 27 \div (351{,}000 \times 5)/100{,}000 = \$1.54$ per 100,000 picks, or, say, $1.50 per 100,000 picks.

It is evident from this formula and example that the work assignment is fixed for the job, and number of looms assigned to an operator, or the speed at which they run, may be altered, if necessary, to make it possible for the operator to produce the number of picks assigned with a satisfactory loom efficiency. In considering a change in loom speed, higher speeds usually, but not always, increase the amount of work per 1,000 picks. The reason for this situation is that more warp and filling breaks usually occur at the higher speeds. Time studies are indicated, whenever a change is made in loom speed, to determine the effect.

After the work assignment has been established by the method given, the number of looms the weaver is to operate can be determined by the following formula:

$$\text{Number of looms} = \frac{\text{Work assignment per work day in picks}}{\begin{bmatrix}\text{Minutes}\\ \text{per work}\\ \text{day}\end{bmatrix}\begin{bmatrix}\text{Loom speed}\\ \text{in picks}\\ \text{per minute}\end{bmatrix}\begin{bmatrix}\dfrac{\text{Loom efficiency}}{100}\end{bmatrix}}$$

The number of minutes in a work day is, for example, $60 \times 8 = 480$ min. for an 8-hr. work day. Loom speed is number of picks thrown by the loom in one minute of full operation. Loom efficiency is percentage of the full work day that the loom actually runs. Excluded from the calculation is the stopped time for warps out, for twisting-in new warps, for repairs other than minor loom fixing, waiting for work, and prolonged absence of the weaver. Included in the calculation is an allowance for the time of interference.

Every weaving job requires that a certain amount of work must be performed while the loom is stopped. The total time required for a loom to produce 1,000 picks is the time required to do the necessary work upon the loom while it is stopped, plus the running time required by the loom to throw 1,000 picks.

If a weaver is required to operate several looms simultaneously, an additional allowance must be made for interference time. Loom interference time is the time a loom is stopped (the stoppage having been caused by its own stop motions or by the weaver) waiting for attention by the weaver. It occurs when two or more looms in a stand are stopped simultaneously. Such stoppages are frequent in loom operation, and the time involved must be allowed for in calculating the number of looms to be assigned to a weaver, else he will be unable to perform the number of minutes of work specified in the work assignment. If a piece rate or incentive wage rate is figured on the work assignment (as com-

puted by a method previously given in the article quoted) and the estimated loom efficiency is figured by a method which does not allow for interference time, the weaver's earnings will be less than the amount that has been estimated.

The time necessary to be allowed for interference varies with the skill and speed of the weaver, and with number of looms in the stand. The greater the weaver's skill and speed the less the interference time; the more looms in the stand the greater the interference time. The correct allowance can best be determined by careful time study and analysis of a sufficient number of jobs to give a creditable finding. One large silk mill has made such a determination and has embodied the results in the chart, Fig. 54. The allowances thus provided for have been demonstrated to be adequate by a long and extensive application.

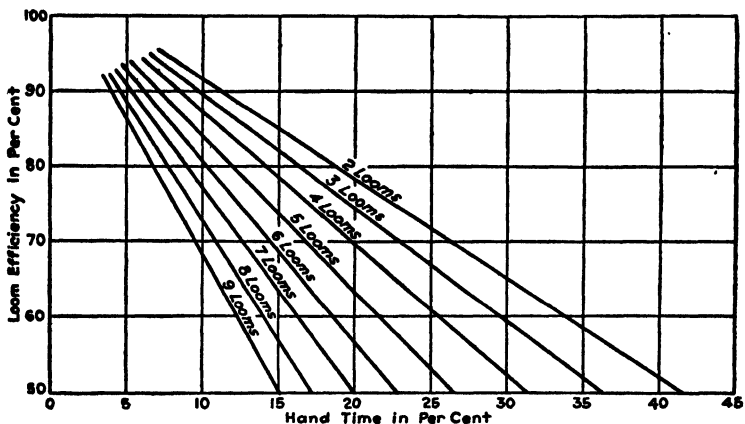



FIG. 54. Relation of Hand Time and Loom Efficiency in Silk and Rayon Weaving

Fig. 54 gives loom efficiency, expressed as a percentage of the possible maximum, that may be expected from loom stands of from two to nine looms, and for various hand-time percentages computed from the following formula:

$$\text{Hand time in per cent} = 100 \times \frac{\text{Time for work while loom is stopped, in minutes per 1,000 picks}}{\left[\begin{array}{l}\text{Time for work while}\\ \text{loom is stopped, in}\\ \text{minutes per 1,000 picks}\end{array}\right] + \left[\begin{array}{l}\text{Machine time}\\ \text{in minutes per}\\ \text{1,000 picks}\end{array}\right]}$$

Use of the formula is illustrated by the following example:

Assume for a plain silk-crepe work assignment 351,000 picks, work day 480 min., loom speed 140 picks per min., time for work while stopped .454 min. per 1,000 picks, machine time 7.142 min. per 1,000 picks, then hand time in per cent $= 100 \; [.454/(.454 + 7.143)] = 6\%$.

From this point on the solution is by approximation or a cut-and-try method. To continue the example:

The corresponding loom efficiency, from Fig. 54, for an 8-loom stand is 85.5%. By computation the number of looms is 351,000 ÷ [(480) (140) (85.5/100)] = 6.11 looms, which is less than the 8 looms assumed.

The corresponding loom efficiency, from Fig. 54, for a 6-loom stand is 90.5%. By computation the number of looms is (351,000) ÷ [(480) (140) (90.5) (90.5/100)] = 5.77, which is approximately the 6 looms assumed.

That is, a weaver should be able to operate six looms on the fabric specified at a loom efficiency of about 87% and throw 351,000 picks in 8 hr., with 12½% of the total time free for personal needs and the relief of fatigue.

AUTOMATIC PRESSES.—Machine assignments and standard times, or piecework prices, for groups of automatic machines are computed at the Winchester Repeating Arms Company by the law of probabilities (Bernstein, Fact. Mgt. & Maint., vol. 99). The reason for using probabilities is that the correct basis may be established by this means from a delay study on any number of machines which are available for study.

In an actual case, where one operator ran 3 and another ran 4 machines, a delay study was made, resulting in the analysis in Fig. 55.

								Total
Machine number	3411	3437	3436	4196	3432	3434	3409	
R.P.M.	115	115	127	119	122	122	135	
Personal delay	1.60	.35	2.50				.65	5.10
Broken tool	111.70			9.90			26.75	148.35
Stocking up[1]	34.45	39.45	53.30	39.50	36.35	43.85	43.15	290.05
Adjust machine	78.85		9.50			33.20		121.55
Machine down[2]	5.40	5.60	11.65	12.00	8.90	5.15	13.30	62.00
Wait for work containers[3]			30.85	10.80	10.00	10.65	11.00	73.30
Total delays	232.00	45.40	107.80	72.20	55.25	92.85	94.85	700.35
Time on study[4]	720.00	720.00	720.00	720.00	720.00	720.00	720.00	5,040.00
Running time	488.00	674.60	612.20	647.80	664.75	627.15	625.15	4,339.65
Efficiency percent	68	93.5	85	90	92.5	87	87	

[1] One machine down only—no loss in efficiency over a 1-machine basis.
[2] Machine down while operator is occupied on another machine that is down.
[3] This item will be eliminated—more containers purchased.
[4] Not continuous—three different days.

FIG. 55. Delay Analysis (7 machines—2 operators) (in minutes)

Bernstein states:

For purposes of multiple-machine basis, only the stocking-up item need be considered in relation to the running time, because on other items the adjuster and not the operator does the work; i.e., on tool or machine breaks. The stocking-up time was 290.05 min. and the running time 4,339.65 min. Therefore, considering only these two items, the stocking-up time, or the time when the operator is occupied, is 6.2% of the total, and the running time is 93.8%. Machine and tool delays amount to 269.90 min., and personal delays are arbitrarily set at 30 man-minutes per working day. Machine and tool delays amount to 5.8% of total time.

Considering only stocking-up (6.2% of total) and running time (93.8%),

Number of Machines	Operator Occupied During Machine Downtime
1	$.062 \times 1 = 6.2$% of time
2	$.062 \times 2 = 12.4$ " "
3	$.062 \times 3 = 18.6$ " "
4	$.062 \times 4 = 24.8$ " "
5	$.062 \times 5 = 31.0$ " "
6	$.062 \times 6 = 37.2$ " "
7	$.062 \times 7 = 43.4$ " "
8	$.062 \times 8 = 49.6$ " "

The 8-machine basis keeps the operator occupied about 50% of the time, allowing the balance of his time for watching his work, getting containers, resting, etc. Thus 8 machines would be the correct assignment, provided cost is satisfactory. For cost analysis purposes the procedure is as follows:

When one machine is down, there is no loss in efficiency on a multiple basis over a unit basis. When 2 machines are down, interference occurs, one machine must wait while the operator attends the other machine.

When 3 machines are down, 2 machines wait while the first is being attended, and one machine waits while the second is attended, a total of 3 machine waits. When 4 machines are down, there are $1 + 2 + 3$ or 6 waits.

On an 8-machine basis, the binomial expansion for 6.2% stocking up and 93.8% running time would be

Binomial Expansion		Machines Down at One Time		Interference
$(.938)^8 \times$	=	.5992	—0	0
$(.938)^7 \times (.062) \times 8$	=	.3170	—1	0
$(.938)^6 \times (.062)^2 \times 28$	=	.0733	—2	$.0733 \times 1 = .0733$
$(.938)^5 \times (.062)^3 \times 56$	=	.0097	—3	$.0097 \times 3 = .0291$
$(.938)^4 \times (.062)^4 \times 70$	=	.0008	—4	$.0008 \times 6 = .0048$
$(.938)^3 \times (.062)^5 \times 56$	=	.0000	—5	
etc.		1.0000		.1072

For the same 8-machine basis, the efficiency would be:

Analysis	Per Cent
One machine down (normal)	6.2
Machines down while operator is occupied	10.7
Tool and machine delays	5.8
Personal delays	5.0
Total Delays	27.7
Efficiency	72.3

Earnings and costs would be as shown in Fig. 56. In the last column of this tabulation, it will be seen that the cost goes down very slowly from a 6-machine basis on, and it should be optional whether the basis adopted is 6, 7 or 8.

Machine Basis	R. P. M.	Eff.	Task	Hourly Earnings	Labor Cost per M
1	122	83.0	6,070	$.45	$.074
2	122	82.6	12,050	.50	.0415
3	122	81.9	18,000	.55	.0305
4	122	80.7	23,600	.60	.0255
5	122	79.2	29,000	.65	.0225
6	122	77.2	33,800	.70	.0205
7	122	75.0	38,400	.75	.0195
8	122	72.3	418,000	.80	.019

Fig. 56. Earnings and Costs on the Basis of Number of Machines Operated

When operator does his own adjusting, the number of machines handled should be fewer. Referring to the first example, the stocking up, adjusting, and attention time will be 11.4% and machine running time will be 88.6%, computed from Fig. 55.

Machine Basis	Operating Adjuster Occupied
4	4 × 11.4 = 45.6%
5	5 × 11.4 = 57.0%

Hence for 4 machines the man is occupied slightly under 50% of his time, which is a fair basis.

Binomial Expansion	Machines Down at One Time	Interference
$(.886)^4 = .6162$	0	0
$(.886)^3 \times (.114) \times 4 = .3171$	1	0
$(.886)^2 \ (.114)^2 \times 6 = .0612$	2	.0612 × 1 = .0612
$(.886)^1 \ (.114)^3 \times 4 = .0053$	3	.0053 × 3 = .0159
$(.114)^4 = .0002$	4	.0002 × 6 = .0012
		.0783

Analysis	Per Cent
One machine down (normal)	11.40
Machines down while operator is occupied	7.83
Personal delays	5.00
	24.23
Efficiency	75.77

Considering only labor cost, would it be better to have an operator handle 4 machines or have an operator-adjuster on 8 machines? Comparative labor costs would be:

Number of Machines	Output at Task	Labor Cost per Hour	Labor Cost per Thousand
8	41,800	1.60	$.038
4	22,100	1.00	.045

The 8-machine basis gives 15% lower labor cost and only 5% lower production.

For a group of machines on which different components are being run and restocking varies greatly, it is a good practice to rate each machine individually, and let the operator run as many machines as he can look after. Suppose earnings per hour for the correct number of machines

is set at $.75. In a group of 10 machines, assume 5 were being run as shown in Fig. 57.

Machine Number	Per Cent Restocking	Correct Machine Basis	Task Earnings per Machine
29323	8.8	5	$.150
29331	6.7	6	.125
30022	4.7	10	.075
30021	16.2	3	.250
29334	5.4	9	.083
Operator's task earnings..............................			.683

FIG. 57. Machine Assignment When Restocking Varies Greatly

To bring his task earnings up to $.75, he should run an additional machine, like #30022 or #29334.

This method works satisfactorily when the efficiency of operation is approximately the same in the new combination of machines, as in the combinations for which the rates were originally set. Otherwise, corrections should be made for the changed efficiencies.

AUTOMATIC SCREW MACHINES.—A method for computing hourly production and standard times for Brown and Sharpe automatic screw machines is given by Varga (Neptune Meter Co.):

$$\text{Standard minutes per piece} = \left[\frac{T}{60} + \frac{.50}{\dfrac{(L \times 12) - K)}{l + l'}}\right]\left[1 + \begin{matrix}\text{Percentage for}\\ \text{tool,}\\ \text{oil, and}\\ \text{general}\\ \text{allowances}\end{matrix}\right]$$

where T = Cam time in seconds per piece, from blueprint
L = Length of bar stock, in feet
K = Scrap, in inches
l = Length of one unit produced, in inches

The tabulations in Figs. 58 and 59 give basic data for the factors K, l' and tool allowances.

Diam. of Material	Values for l'			K	
	Mach. No.	Metallic Material without hole	Metallic Material with hole	Mach. No.	Length of Scrap
.062 to .312.........	00	.055	.055	00	1-3/4
.343 " .500..........	0	.072	.072	0	2-3/8
.531 " .875..........	2	.080	.100	2	2-15/16
.875 " 1.000..........	2	.100	.100	2	2-15/16
1.032 " 2.000..........	—	.125	.125	—	2-15/16

FIG. 58. Factors K and l' for Automatic Screw Machine Calculations

Note: When facing tool is used add .01 to above values of l'. Rod Lengths: Brass = 12 ft. All others = 10 ft.

Tool	Metal Being Machined		
	Brass	Steel	Monel
Cut off	.490	1.850	2.600
Form	1.400	2.070	2.740
Position	.035	.035	.035
Spot face	.029	.043	.049
Drill	.390	.660	.930
Reamer	.160	.205	.250
Box	1.040	1.540	1.750
Die	.240	.243	.246
Tap	.080	.119	.135
Swing	2.500	3.700	4.200
Slotter	.033	.048	.055
General	8.000	8.000	8.000
Oil	2.000		
Inspect	.950		

FIG. 59. Tool Allowances—Automatic Screw Machines

Procedure for Setting a Standard.—In setting a standard on a job of this kind, the following procedure is followed:

1. From operation sheets obtain cam time to produce piece and the class of machine job is run on.
2. Apply formula. Refer to tables for values of l' and K. Compute time to produce piece including the .50 min. for loading the rod. Compute the rod time which equals the product of the time per piece and the number of pieces in the rod.
3. List tools required to machine part. Refer to table of tool allowances and list corresponding percentage tool allowances for given material. List general allowances. Refer to "Rod and Tool Adjustment Allowance" chart, and obtain percent allowance for rod running out and also overall allowance on tool adjustments. Total these allowances.
4. Increase time to produce piece by these allowances.
5. Convert standard time into production per hour.

$$\frac{60}{\text{Standard time}} = \text{Pieces per hour}$$

Illustration: Part: Steel hand shaft. 9/16″ diameter, steel. Run on No. 2 B. & S. screw machine.

Given: $T = 35$ sec., $l = 2\frac{1}{4}$ in., $L = 10$ ft.

$$\frac{T}{60} + \frac{.50}{\dfrac{(L \times 12) - K}{l + l'}}$$

$$= \frac{35}{60} + \frac{.50}{\dfrac{120 - 2\ 15/16}{2.25 + .080}}$$

$$= .583 + \frac{.50}{50}$$

$$= .583 + .01 = .593$$

Rod time $= 50 \times .593 = 29.65$ min.

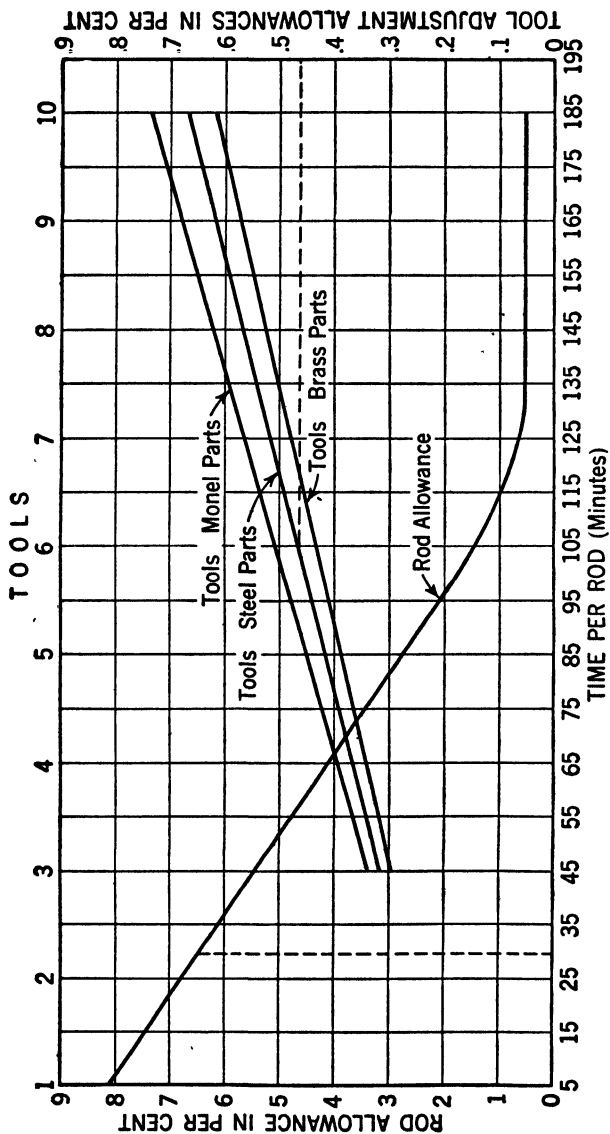



FIG. 60. Rod (Bar Stock) and Tool Adjustment Allowances for Automatic Screw Machine Work
(G. M. Varga)

Allowances	Percentage
Cut off	1.85
Form	2.07
Position	.035
2 box	3.08
Die	.243
Oil	2.00
Inspect	.95
General	8.00
Tool adjustment	.465 (from Fig. 60)
Rod	6.50 (from Fig. 60)
(Includes Interference)	
	25.193

Standard time = .593 × 1.2519 = .742 min. per piece

Production per hour for 1 machine = 81 pieces
Production per hour for 2 machines = 162 pieces
" " " 3 " = 243 "

TEAM OR GROUP WORK.—Where two or more operators work together on the same unit of production, there must be close balancing, that is, synchronizing, or one operator will be idle part of the time. Synchronizing is difficult but not a matter of refinement. When the best possible synchronization has been established, the group time is limited by the longest subdivision or by the slowest individual. Timing should be done on a single individual because it is seldom that all workers involved start and stop at the same point in the operation. There is some overlapping and consequently the true time of the cycle is measured between corresponding points on the cycle of one worker.

Where it is feasible to measure the output of an individual, individual tasks are to be preferred to group tasks, both because of the above mentioned limitation and because of the greater strength of individual incentives. There are cases, for instance emergency repair, in which a group of employees work on the same job and where it is difficult to measure the output of the individual; and there are cases, particularly in the automobile industry, where models change frequently, high output is demanded, and there is insufficient time to study and set individual tasks.

When group jobs are reasonably stable, each individual job in the group should be studied separately, or better yet, the time should be synthesized from unit data, and time allowances figured. Time allowances for all individual jobs constituting a group job should be made to reapportion elementary operations in such a manner that the individual times would be approximately equal. In cases where reapportionment of work between members of the group is impossible, a study of the longest part is all that is necessary. In such cases the output of this portion will be the output of the group. It is sometimes possible to place a second employee on the longest subdivision of the job and apportion the balance of the work so that the time required of each of the others is approximately half the time required for the longest subdivision.

SECTION 8

MOTION STUDY—WORK SIMPLIFICATION

CONTENTS

PAGE

Operator Right- and Left-Hand Process Chart

Micromotion Study

PAGE

Motion-Time Analysis

Selection of Motion-Picture Equipment

Research Equipment

Applying Work Simplification

SECTION 8

MOTION STUDY—WORK SIMPLIFICATION

MOTION STUDY DEFINED.—

> "Motion study is the science of eliminating wastefulness resulting from using unnecessary, ill-directed, and inefficient motions. The aim of motion study is to find and perpetuate the scheme of least-waste methods of labor." (F. B. and L. M. Gilbreth, Primer of Scientific Management)

Another definition by the same authors indicates a procedure:

> "Motion study consists of dividing work into most fundamental elements possible; studying these elements separately and in relation to one another; and from these studied elements when timed, building methods of least waste." (Applied Motion Study)

As practiced by the Gilbreths, motion study included an analysis of the flow and processing of material and paper work and the movements of men as well as the study of the fundamental elements of each worker's job. For these basic factors they developed the flow process charts and the operator's motion-cycle charts of the two hands.

WORK SIMPLIFICATION.—Since there has been a tendency to limit the term "motion study" to the details of the worker's job, the term "work simplification" is coming into accepted use as one which best describes and embraces the fields of process analysis, simple motion study, and micromotion study. These three fields represent degrees of refinement in the application of the analytic method to the problem of work simplification, and are presented in the order in which they should be used. Just as it is necessary to use tools in a certain order to perform a given job, so it is imperative to use the tools of analysis and measurement in their correct order. It would be foolish to apply the refinements of a micromotion study to an operation before finding out through a process analysis whether the operation was necessary or whether it could be better done in an entirely different way.

Process Analysis

DEFINITION.—Process analysis may be defined as the subdivision or resolution of a manufacturing process or office procedure into its constituent operations and attendant material movements, so that each operation and material handling may be studied and its necessity and effectiveness in furthering the process determined.

COLLECTING DATA BY OBSERVATION.—In collecting the data for a process analysis it is necessary for the investigator to trace and verify every step in the process. This work cannot be done by sitting at a desk and consulting route sheets in a planning office, but must entail actual observation on the floor of the shop and consultation with foremen and workers. It requires a great deal of patience and attention to accuracy of details on the part of the investigator. When completed, the analysis contains a fund of information not previously known before by any single individual in the plant. This information, collected at every step, must satisfy the six questions: What? Why? How? Who? Where? and When?

What Is Being Done and Why?—With respect to each operation in the process, it is important to know exactly "what" is being done to the material, and "why" it is being done. Frequently it is revealed that there is no valid reason for performing an operation. "How" it is done refers to equipment and tools used, and "who" refers to the type or classification of employees performing the job. "Where" considers the exact location of the work in the plant with the distances between operations, and "when" refers to the sequence of the operations in the process, or a definite time at which an operation must be performed. The minute details or motion elements of job performance are not recorded at this time because the results of process analysis may eliminate some and so completely transform other operations that those details would be meaningless and the effort spent in their collection would be wasted.

CHARTS AND SYMBOLS.—The presentation of a process analysis is best made by one or more of the types of process charts, employing symbols by means of which the study can be carried on. There has been a definite tendency toward a reduction in the number of categories into which events appearing on a process chart will be classified. The minimum number of events is four—operation, transportation, storage, and inspection. A fifth—delay—seems desirable in some cases.

The definitions of the types of process charts which are used in the following text, and the symbols used on them, are those which the Special Committee of the American Society of Mechanical Engineers on the Standardization of Therbligs, Process Charts, and Their Symbols have had under consideration, and represent the best thinking at the present time.

Process Chart.—"A process chart is a graphic representation of events and information pertaining thereto occurring during a series of actions or operations." Symbols are employed to represent the events and those most commonly used are shown in Fig. 1.

Operation.—The circle in Fig. 1 designates an operation, which is defined as follows: "An operation occurs when an object is intentionally changed in any of its physical or chemical characteristics, is assembled with or disassembled from another object, or is arranged or prepared for another operation, transportation, inspection, or storage. An **operation** also occurs when information is given or received or when planning or calculating takes place."

Transportation.—The halfsquare-semicircle placed vertically with the square section upwards designates a transportation, which is said to occur "when an object is moved from one place to another except when such movements are caused by the process or by the operator at the work station during an operation or an inspection." A letter is sometimes placed within the symbol to indicate the means of conveyance, as M for man, C for conveyor, E for elevator, K for truck, etc.

Storage.—The single triangle with apex downward indicates storage. "A storage occurs when an object is kept and protected against unauthorized removal."

Inspection.—The square is used to represent an inspection, which is said to occur "when an object is examined for identification, verified for quality or quantity, or measured in any of its characteristics."

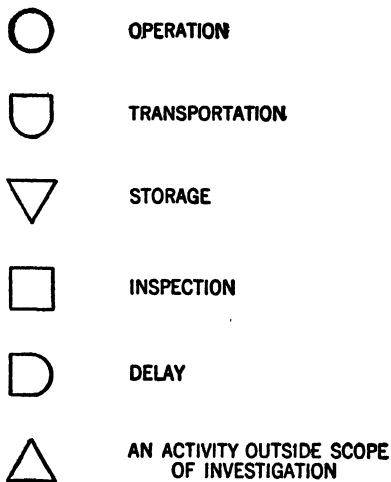



Fig. 1. Process Chart Symbols

Delay.—The halfsquare-semicircle on its side is used to indicate delay. "A delay occurs to an object when conditions except those of processing do not permit or require immediate performance of the next planned action."

Activity Outside Scope of Investigation.—The triangle with apex upward is used for an activity beyond the scope of a motion study investigation. "An **activity** outside of the scope of the investigation is an operation, transportation, inspection, delay, storage, or series of these which for any reason the investigator considers unnecessary or impractical to analyze during the current study."

Clarification of Definitions.—When unusual situations outside the range of the definitions are encountered, the intent of the definitions

summarized in the following tabulation will enable the analyst to make the proper classifications.

Classification	Predominant Result
Operation	Produces or Accomplishes
Transportation	Moves
Inspection	Verifies
Delay	Interferes
Storage	Keeps

Former Symbols.—Since these symbols are a new development just being introduced into use, there are many process charts in existence which employ the symbols as somewhat generally used up to the present time. Thus, a small circle has been employed to designate transportation. Storage and delay have both been symbolized by a triangle, the reason being that delay was considered as keeping an item where it was, therefore under "storage." Delay or temporary storage sometimes has been indicated by double concentric triangles. The square placed on its side indicated inspection for quantity, but when on its corner it indicated inspection for quality. The charts in this Section, being actual cases, for the most part use the symbols in their former designations.

Although the symbols as described above are most widely used, there is one school of practice that has discarded symbols in favor of letters. It uses O, T, I, S, which are the first letters of the words operation, transportation, inspection, and storage.

OPERATION PROCESS CHART.—The first step in process analysis is the subdivision of a manufacturing process into its separate operations and inspections, or of an office procedure into its clerical functions. When the process consists of the manufacture and assembly of several component parts, each with a series of operations, or of clerical operations performed on several related forms, the relation between these facts and events can best be shown by the operation process chart. This chart is "a graphic representation of the points at which materials are introduced into the process, and of the sequence of inspections and all operations except those involved in material handling. It includes information considered desirable for analysis such as time required and location." Fig. 2 is such a chart and shows the sequence of process operations on each component part and the place where each enters a subassembly and final assembly, and the time of performance of each operation. The chart aids in the quick visualization of these relationships, and, most important of all, it serves as a basis for study of all the operations with a view toward their elimination, combination, or a change in sequence which would simplify the process.

Operation process charts vary greatly in complexity and are, therefore, usually drawn on plain sheets of paper of sufficient size to accommodate the chart. They may be provided with a printed heading for identification data.

FLOW PROCESS CHART.—The second stage in process analysis introduces the details of storing, handling, and moving the material between manufacturing operations. This information is shown on a flow process chart which is "a graphic representation of the sequence of all operations, transportations, inspections, delays, and storages occurring during a process or procedure, and includes information considered

FIG. 2. Operation Process Chart for Manufacture and Assembly
(Lowry, Maynard, and Stegemerten, Time and Motion Study)

CHART TYPE PROCESS FLOW CHART — DATE DECEMBER 19—
SUBJECT CHARTED CLOTH TAPE — CHART BY D.B.P.
OPERATION SEWING LOOPS FOR FILTER CLOTHS — CHART NO. 1
DEPARTMENT FILTER CLOTHS — SHEET NO. ___ OF ___

CHART SYMBOLS:— ○ = OPERATION; TRANSPORTATION; □ = INSPECTION; ▽ = STORAGE; D = DELAY

DIST. IN FEET	TIME IN MINS.	CHART SYMBOLS	PROCESS DESCRIPTION
			OLD METHOD
		D	REELS OF TAPE IN RACK AT END OF CUTTING TABLE
6'		TRANSPORTATION	TAPE TO FRONT OF OPERATOR (TAPE UNWOUND BY HAND - 3 REELS AT A TIME)
		1	MEASURE AND CUT TAPES TO LENGTH (3 STRIPS AT A TIME)
		D	STRIPS OF TAPE IN PILE AT ELECTRIC CUTTER
		2	STACK STRIPS OF TAPE NEATLY IN BUNDLE
50'		TRANSPORTATION	BUNDLE OF TAPES TO SEWING MACHINE
		3	LOOP AND SEW STRIPS OF TAPE (ENDS TRIMMED AUTOMATICALLY)
		D	LOOPS IN PILE BEHIND SEWING MACHINE
			NEW METHOD
		D	REEL OF TAPE IN RACK AT END OF SEWING MACHINE TABLE
2'		TRANSPORTATION	TAPE TO LOOPING FIXTURE (TAPE UNWOUND BY HAND - 1 REEL AT A TIME)
		1	LOOP AND SEW TAPE (LOOPING FIXTURE MEASURES TAPE, TRIMMING ATTACHMENT CUTS AND TRIMS ENDS OF LOOPS)
		D	LOOPS IN PILE BEHIND SEWING MACHINE

SUMMARY

	OLD METHOD	NEW METHOD	SAVINGS
NUMBER OF OPERATIONS	3	1	2
NUMBER OF TRANSPORTATIONS	2	1	1
NUMBER OF STORAGES	3	2	1
TOTAL DISTANCE TRAVELED	56'	2'	54'

FIG. 3. Material-Flow Process Chart

desirable for analysis such as time required and distance moved." It appears in two forms, the material type which "presents the process in terms of the events which occur to the material," and the man type which "presents the process in terms of the activities of the man."

At this point the meaning of "operation" is extended beyond its reference to a manufacturing transformation to include any labor spent on material, such as picking up and putting down, loading and unloading, and a man's actions other than his transportation.

MATERIAL-FLOW PROCESS CHART.—A material-flow process chart shows the sequence of all operations and inspections performed on an item of material, and its transportation, with distances and storages, until it reaches a finished state in stock or enters into an assembly. In this sequence of operations other materials or parts may enter the process, and byproducts be given off from it. The chart is really an expansion of one of the component lines of the operation process chart, adding to that chart the details of handling the material. Fig. 3 is such a chart of an **old and new method for sewing loops.** It provides columns for recording distances traveled, and times taken, in addition to columns for the symbols and descriptions. An important part of this chart is the summary which shows the total number of events occurring within each category and the distance traveled, together with the savings effected in each by a proposed new method. Such summaries are an aid in making comparisons between alternative proposed methods.

VARIATIONS IN CHARTS.—Although the labor of drawing the symbols has been simplified through the use of plastic templates, the elimination of this labor altogether would certainly be an example of applying work simplification to one of its own procedures. This step has been accomplished by providing chart forms with the symbols printed thereon in outline. Fig. 4 constitutes a chart of this type which has been widely used in the aircraft industry. It carries **four columns of symbols** representing the four classifications of events. It is necessary for the observer making the chart merely to select the appropriate symbol opposite each line of description and then to connect each successive symbol with a heavy line. The symbols may be left in outline form, or may be filled in solid for the added emphasis which this gives to them. One practice fills in only the process operation symbols. The line connecting the symbols directs the eye of the reader and helps to locate the next symbol in the appropriate column. Each event is therefore designated by a symbol and by the position of that symbol in one of four columns. This double means of designation, by symbol and by position, makes an effective graphic chart. Another feature is the placing of both present and proposed methods in parallel columns. This plan facilitates comparison.

Fig. 5 is an example of the complete flow process chart which is recommended by the Committee on Standardization of Therbligs, Process Charts and Their Symbols.

It is possible to give up the use of symbols and to **rely on position to designate the action.** Figs. 6a and 6b have four columns headed by the letters O, T, I, S for the same four classifications as in the previous chart. Points are spotted in the appropriate columns to designate the type of action for each of the events described on successive horizontal lines.

PROCESS CHART

VULTEE AIRCRAFT, INC.

NASHVILLE DIVISION

SUBJECT CHARTED Typical Painted Part
CHARTED BY R. N. Spaulding
CHART No. 1 SHEET No. 1
Transported by conveyor unless otherwise noted

DATE March 13 194
PLANT Nashville
DEPT. 96

SUMMARY			
METHOD	PRES.	PROP.	SAVING
No. of operations	19	6	13
No. of transportation	10	7	3
No. of storages	7	3	4
No. of inspections	0	0	-
Man hours	2.04	1.55	.49
Distance travelled	211	198	13
Total cost			

Dist in feet	Time in min	Operation	Transp.	Storage	Inspect	Description of present method	Dist. in feet	Time in min	Operation	Transp.	Storage	Inspect.	Description of proposed method
				●		At Production Control Bench					●		At Production Control Bench
4	.10		●			To Conveyor (10 pieces by hand)	4	.10		●			To conveyor (10 pieces by hand)
	.20	●				Place on screen		.20	●				Place on screen
15			●			To first spray booth	15			●			To first spray booth
	.05	●				Spray 1st side (10 pieces)		.10	●				Spray all four sides (using four
	.02	●				Turn screen 90°			⋮				spray heads superimposed on con-
	.05	●				Spray 2nd side	40		⋮				veyor.)
	.02	●				Turn screen 90°		.20		●			To turning position
	.05	●				Spray 3rd side	10		●				Parts turned over
	.02	●				Turn screen 90°		.10		●			To second spray booth
	.05	●				Spray 4th side	75		●				Spray all four sides
	.02	●				Turn to starting position		.10		●			To stock room
40			●			To turning position	4	.10	●				Counted as taken from conveyor

	.20	● ○ △ □	Parts turned over			○ ● △ □	To bench (hand)
10		○ ● △ □	To second spray booth	50	.55	○ ○ ▲ □	On bench
	.05	● ○ △ □	Spray 1st side		.10	○ ● △ □	To bins
	.02	● ○ △ □	Turn screen 90°			● ○ △ □	Place in bins
	.05	● ○ △ □	Spray 2nd side			○ ○ ▲ □	In bins
	.05	● ○ △ □	Spray 4th side			○ ○ △ □	
75		○ ● △ □	To unloading position			○ ○ △ □	
4	.10	○ ● △ □	To bench -hand-			○ ○ △ □	
		○ ○ ▲ □	On bench			○ ○ △ □	
4	.10	○ ● △ □	To truck - hand			○ ○ △ □	
		○ ○ ▲ □	On truck			○ ○ △ □	
25		○ ● △ □	To Process Stores - truck			○ ○ △ □	
		○ ○ ▲ □	On truck			○ ○ △ □	
4	.10	○ ● △ □	To bench - hand			○ ○ △ □	
		○ ○ ▲ □	On bench			○ ○ △ □	
	.10	● ○ △ □	Parts counted			○ ○ △ □	
		○ ○ ▲ □	On bench			○ ○ △ □	
30	.50	○ ● △ □	To stores - hand			○ ○ △ □	
	.10	● ○ △ □	Place in bins			○ ○ △ □	
		○ ○ ▲ □	In bins			○ ○ △ □	
		○ ○ △ □				○ ○ △ □	
211	2.04	19-10-7-0	← TOTAL	198	1.55	6-7-3-0	← TOTAL

FIG. 4. Flow Process Chart with Symbol Columns
(Courtesy of A. H. Mogensen)

FLOW PRO

IDENTIFICATION

SUBJECT CHARTED: Relief Valve Body

DRAWING NO: A - 520612   PART NO: 16150

POINT AT WHICH CHART BEGINS: Receipt of requisition from machine shop

LOCATION: Bar Stock Storeroom

POINT AT WHICH CHART ENDS: Storing of finished product in storeroom

LOCATION: Assembly Dept. Storeroom

CHART NO. 1021

TYPE OF CHART: Material

SHEET NO. 1 OF 1 SHEETS

CHARTED BY: J. Smith

DATE: 9-8-

APPROVED BY: J. Jones

DATE: 9-8-

QUANTITY INFORMATION

1 Bar makes 50 bodies

1 Packing box holds 25 bodies

YEARLY PRODUCTION: 100,000 Pieces

COST UNIT: 1 Valve Body

PRESENT METHOD

Quantity Unit Charted	Symbols	Description of Event	Dist Moved in Feet	Unit Oper. Time in Hrs.	Unit Transp. Time in Hrs.	Unit Inspect Time in Hrs.	Delay Time in Hrs.	Storage Time in Hrs.
1 Bar	Operation 1	Bar loaded on truck upon receipt of requisition from machine shop (2 men)	10	.0002				
20 Bars	Transport 1	Moved to #201 machine	210		.0002			
1 Bar	Operation 2	Bar unloaded to bar stock rack near #201 machine (2 men)	10	.0002				
	Delay 1	Bar waits for operation to begin					4.00	
1 Valve Body	Operation 3	Drill, bore, tap, seat, file, and cut off	8	.0550				
	Delay 2	Await moveman					4.00	
300 Valve Bodies	Transport 2	Moved to burring department	300		.0011			
	Delay 3	Await burring operator					1.50	
1 Valve Body	Operation 4	Burr	6	.0075				
	Delay 4	Await moveman					2.00	
300 Valve Bodies	Transport 3	Moved to drill press in machine shop	320		.0011			
	Delay 5	Await drilling operator					2.00	
1 Valve Body	Operation 5	Drill and countersink 8 holes	8	.0480				
	Delay 6	Await moveman					4.00	
300 Valve Bodies	Transport 4	Moved to inspection department	100		.0001			
	Delay 7	Await inspector					1.50	
1 Valve Body	Inspection 1	Inspect and gauge	8			.0085		
	Delay 8	Await moveman					2.00	
300 Valve Bodies	Transport 5	Moved to storeroom #2	3000		.0030			
	Storage 1	Storage until requisitioned by detail dept.						48.0
300 Valve Bodies	Transport 6	Moved to seat lapping machine	2560		.0025			
	Delay 9	Await operator					1.50	
1 Valve Body	Operation 6 / Inspection 2	Lap seat and test	6	.1700				
	Delay 10	Await moveman					2.00	
400 Valve Bodies	Transport 7	Moved to paint booth	400		.0004			
	Delay 11	Await painter					4.00	
1 Valve Body	Operation 7	Mask, prime, paint, dry, and unmask	10	.0350				
100 Valve Bodies	Transport 8	Carried to packer by painter	125		.0001			
	Delay 12	Await packing					2.00	
1 Valve Body	Operation 8	Pack in box	12	.0100				
[illegible] Valve Bodies	Transport 9	Sent by conveyor to assembly department Storeroom	300					
	Storage 2	Storage until requisitioned						60.0

FIG. 5. Flow Process Chart of a Present and a Proposed Method

ESS CHART

SUMMARY

		Present Method		Proposed Method		Difference	
TOTAL YEARLY SAVING—DIRECT LABOR: $2200.00	UNIT COST DIRECT LABOR & INSP	.300		.278		.022	
	DISTANCE TRAVELED IN FEET	7383		1843		5540	
INSTALLATION COST OF PROPOSED METHOD: $150.00		NO	TIME IN Hrs.	NO.	TIME IN Hrs.	NO.	TIME IN Hrs.
	○ OPERATIONS	8	.3259	7	.3084	1	.0175
	TRANSPORTATIONS	9	.0085	6	.00222	3	.00628
ESTIMATED NET SAVING—FIRST YEAR: $2050.00	□ INSPECTIONS	2	.0085	1		1	.0085
	D DELAYS	12	31.5	8	25.5	4	6.0
	▽ STORAGES	2	108.0	1	60.0	1	48.0

PROPOSED METHOD

Quantity Unit Charted	Symbols	Description of Event	Dist Moved in Feet	Unit Oper. Time in Hrs.	Unit Transp Time in Hrs.	Unit Inspect Time in Hrs.	Delay Time in Hrs.	Storage Time in Hrs.
1 Bar	○ 1	Bar loaded on truck upon receipt of requisition from machine shop (2 men)	10	.0002				
20 Bars	◡ 1	Moved to #301 machine	210		.0002			
1 Bar	○ 2	Bar unloaded to bar stock rack near #301 machine	10	.0002				
	D 1	Bar waits for operation to begin					4.00	
1 Valve Body	○ 3	Drill, bore, tap, seat, file, and cut off	8	.0550				
	D 2	Await drill press operator					2.00	
100 Valve Bodies	◡ 2	Moved to drill press by operator	20		.00002			
1 Valve Body	○ 4	Drill 8 holes	8	.0350				
	D 3	Await moveman					2.00	
300 Valve Bodies	◡ 3	Moved to burring department	300		.0011			
	D 4	Await burring operator					1.50	
1 Valve Body	○ 5	Burr	6	.0100				
	D 5	Await moveman					2.00	
300 Valve Bodies	◡ 4	Moved to seat lapping machine - detail dept.	550		.0005			
	D 6	Await operator					6.00	
1 Valve Body	○ 6 □ 1	Lap, seat, test, and inspect	6	.1700				
	D 7	Await moveman					2.00	
100 Valve Bodies	◡ 5	Moved to paint booth	400		.0004			
	D 8	Await painter					6.00	
1 Valve Body	○ 7	Mask, prime, paint, dry, unmask, and pack in box	15	.0380				
[illegible] Valve Bodies	◡ 6	Sent by conveyor to assembly department storeroom	325					
	▽ 1	Storage until requisitioned						60.0

using Symbols Recommended by the Committee on Standardization

RCA MFG. CO INC., HARRISON, N. J.

FLOW PROCESS CHART
Page No 1 of 2

SUBJECT CHARTED STORAGE OF PLATED ARMCO WIRE

DATE STARTED 6/16/—

CHARTED BY John Czarkowski

OPERATION DELIVERY FROM PLATING ROOM TO WAREHOUSE

FACTORY NO 8 DEPT. 868

WHY? WHAT? WHEN? WHERE? WHO? HOW?

Operation Transportation Inspection Storage
(solid black) (shaded)
White = Do Red = Storage Blue = Make Ready and Put Away

1. ELIMINATE?
2. COMBINE?
3 CHANGE THE SEQUENCE?
4 SIMPLIFY?

DATE CHARTED			PRESENT METHOD		DATE CHARTED			IMPROVED METHOD
Dist. Feet	Time Min.	Draw Line or Number	PROCESS SEQUENCE	Color	Dist Feet	Time Min.	Draw Line or Number	PROCESS SEQUENCE
		O T I S	On skid in plating room				O T I S	On pallet in plating room
			Place hand truck under skid					Gas truck under pallet
			Lift skid					Lift load
173			To elevator		173			To elevator
			Wait for elevator					Wait for elevator
8			Into elevator		8			Into elevator
14			Down to street level		14			Down to street level
188			To elevator Bldg. 34		165			To Sixth St. gate
			Wait for elevator					Give pass to gateman
8			Into elevator		250			To warehouse
3		O T I S	Up to platform				O T I S	Lift load
20			To side of platform					Place on lift truck
			Lower skid to platform		8			Into elevator
			Remove truck from under skid		8			Down to basement
	½ to 6 hrs.		Wait for hired truck		40			To storage space
			Place truck under skid					Place on floor
			Lift skid					Remove hand truck
25			Into hired truck					Wire in storage on floor
			Lower skid					
			Remove hand truck					
208		O T I S	To Sixth St. gate				O T I S	
			Sign book (Trucker)					
250			To warehouse					
20			Back truck to platform					
			Place truck under skid					
			Lift skid					
12			Into warehouse					
12			Back into elevator					
6			Down to basement					
40			To storage space					
			Lower skid					
			Remove hand truck					
			Wire in storage on floor					

FIG. 6a. Flow Process Chart with Letter Columns
(Courtesy of L. E. Mitchel, R.C.A.)

RCA MFG CO INC, HARRISON, N J.

PROCESS CHART — PAGE NO 2

SUMMARY — DATE COMPLETED 7/17/–

DESCRIPTION	METHOD		SAVING	
	PRESENT	IMPROVED		CHARTED BY John Czarkowski
Number of DO operations	0	0	0	
" " M R & P A operations	12	6	6	GROUP LEADER
" " transportations	15	8	7	
" " inspections	0	0	0	COOPERATORS ON (Improved Method)
" " storages	6	4	2	Walter Hoffman
Total Distance—Feet	989	666	323	Norman Hallowell
" Time—Minutes	45	20	25	
" Cost of Process				

Additional Information on Savings

Recommendations and Sketches

WORK SIMPLIFICATION
RCA MANUFACTURING CO INC, HARRISON, N J

FIG. 6b. Flow Process Chart with Letter Columns (*cont'd*)

These points are then connected by a heavy line which makes the location of each point easier to discern. This chart provides a color column which is designed to aid in the further classification of events into those useful operations, called "do," which advance the process, the storages or delays, and the make-ready and put-away. It also embodies the feature of placing both present and improved methods side by side for comparison. The heading includes the six questions which should be known about every step on the chart as a reminder for the chart makers, and the four questions which are used by the analysts to challenge every step.

PARALLEL FLOW OF SEVERAL COMPONENTS.—The flow charts exhibited thus far trace the events on one class of material, but sometimes these charts show the parallel flow of several component parts through their respective operations and their union in subassemblies and final assembly. Charts of this type are operation process charts that have been expanded to include the details of material handling and movement. Fig. 7 is such a chart for a proposed method on a subassembly consisting of two pieces. The summary on this chart shows a remarkable reduction in the number of events and the distance trav-

DESCRIPTION		PRES		PROP	
NO OF OPERATIONS		32		7	
NO OF OPERATIONS ON COST		3		2	
NO OF TEMPORARY STORAGES		25		5	
NO OF INSPECTIONS		1		1	
NO OF TRANSPORTATIONS	BY MAN	25	42	6	8
	" TRUCK	13		1	
	" ELEVATOR	3		0	
	" CONVEYOR	1		1	
TOTAL NO OF OPERATION-TEMP STORAGES-INSPECT-TRANSPORT.		120		21	
TOTAL DISTANCE TRAVELED		2409		372.5	

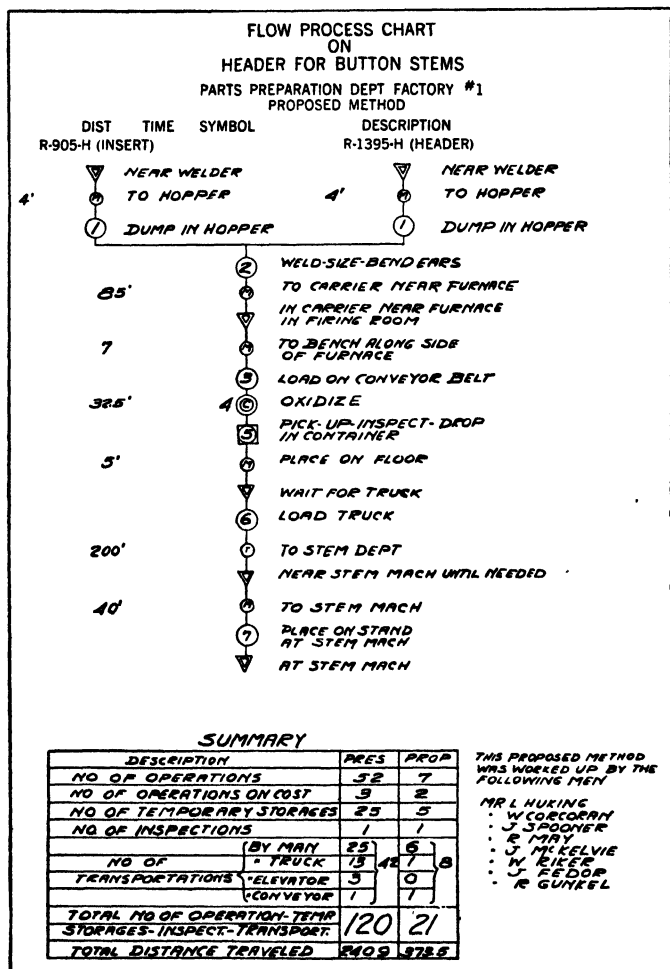



FIG. 7. Flow Process Chart for Two Components
(Courtesy of W. A. Hoffman, R.C.A. Mfg. Co., Inc.)

eled. Were the present method shown, the chart would be six times as long, requiring that many pages of this Handbook to reproduce if drawn to the same scale.

The "present method" consisted of the following process operations: (1) weld, (2) oxidize, (3) size and bend ears, (4) wash three times, (5) oven dry. The simplification which is effected in the proposed method is in direct answer to the four questions always asked at each step in the process, "Can we eliminate, combine, change the sequence, or simplify?"

The proposed method eliminates the washing and drying operations which were made necessary by the oil from the sizing and bending operation. The removal of the oil is accomplished by changing the sequence of the sizing and bending operation so that it precedes the oxidizing, which removes the oil. It was also found possible to combine the sizing and bending with the welding operation. These simple changes, made almost without cost, eliminated over 2,000 ft. of travel and innumerable handlings and storages. A significant feature of the charts prepared by this company is the inclusion of the **names of those individuals who collaborated** in working up the proposed method. Fig. 6a is another example which also includes the name of the one who drew the chart. The psychological advantage of this procedure is apparent: It places the responsibility and hence gives credit where due.

FLOW PROCESS CHARTS WITH FLOW DIAGRAMS.—Fig. 8 is an example of the multiple parts type of flow chart with the addition of the flow diagram. This combination is possible where the layout diagram is compact and can be conveniently introduced into a corner or at the bottom of the flow chart. Usually the flow diagram is drawn separately. It may be said here that the first step in making a plant layout is the preparation of the flow process chart, then the flow diagram, and finally the actual template layout.

Since the number of parts entering into an assembly may vary greatly, it is impossible to standardize these charts as to size. Each one must be individually designed or laid out so as best to present its message. They have even been made to cover an entire wall.

The prepared form lends itself to charting the events occurring to a single item of material or the activities of a single person. They may be designed for charting one method, or two methods, the present and proposed. These forms are printed usually on the following sizes of sheets: 8½ x 11 in., 11 x 17 in., and 17 x 22 in., which file in the standard letter file, and 8½ x 14 in. and 14 x 17 in., which file in the legal file.

FLOW PROCESS CHARTS OF ROUTINE OPERATION PROCEDURES.—Flow process charts are applied to office procedures. Clerical operations performed on forms and records are charted in the same way that process operations are charted for materials. The various forms move or flow from one posting, comparing, computing, or checking operation to another. Usually the portraying of an office procedure involves the charting of several clerical operations that are performed on a number of related forms. For this reason the chart will be especially designed for each situation, and printed chart forms cannot be used except in limited cases.

The use of symbols for showing office procedures has been carried to a higher degree of specialization and refinement than is usually found

NEW METHOD
FLOW PROCESS CHART
ON
RELAY ASSEMBLY SMB-1
FROM: RAW STORES
TO: FINISHED STORES
FIBRE BLOCK
TRAVEL
OPERATION DESCRIPTION
IN RAW STORES
5 FT.
TO DRILL PRESS
1
MULTIPLE DRILL PRESS
DRILL 4-1/8" HOLES
2
DRILL 4-3/16" HOLES
3
COUNTER SUNK 1/4"
WAIT (BOXES ON BENCH)
4
RIVETING RELAY & TERMINALS ON BLOCK
WAIT (BOXES ON BENCH)
5
SOLDEREDRELAY LUGS ON TERMINALS
6
FINAL TESTING & ADJUSTING OF RELAY
RELAYS, TERMINALS & RIVETS
OPERATION DESCRIPTION
IN RAW STORES
TESTING & CHECKING
TO RIVETING BENCH WITHIN ARM REACH
SOLDER & FLUX
OPERATION DESCRIPTION
IN RAW STORES
CHECK QUANTITY
TO SOLDERING BENCH WITHIN ARM REACH

FIG. 8. New Method Flow Process Chart on Relay Assembly

PROCEDURE CHART SYMBOLS FOR OFFICE OPERATIONS

Transmittal

Send by messenger

Deliver personally

Miscellaneous operation for which there is no specific symbol

Subsequent operations on indicated documents or process not necessary to the particular chart

Fill in form

Prepares letter report, etc

A subsequent return to the flow of indicated documents from a unit whose particular operations are not important to the instant chart.

Sign letter, memo, etc.

Type.

Voucher preparation.

Time-stamp. (Also indicates date stamp.)

Numbered, stamped, etc.

Perforation, such as Cancellation of a security or coupon, or affixing dates

Posting in ledger, journal, etc (By hand)

Posting in ledger, journal, etc (By machine.)

Record in diary

Sort.

Assemble.

Destroyed.

Distribute to two or more people.

Confer - two or more people working together.

Note and sign. (Surname.)

Transmit information by telephone.

Search of temporary file.

Search of permanent file.

Received.

Receive information by telephone

File temporarily

File permanently

Check for quantity.

Check for quality

Check for both quantity and quality (Examine)

Inspect for quantity and perform operation.

Inspect for quality and perform operation. (Select, check, and make entry.)

Approve, (Administrator's or Division Head's perfunctory signature-Actual, official final approval by anyone.)

Extension proof or other mechanical check of an arithmetic operation.

Document, form or other paper. For example, [1/3 F1-149] means original and three copies of Form F1-149

Discontinuity; intervening functions unimportant to the chart.

FIG. 9a. Symbols for Charts of Office Procedures

FIG. 9b. Chart of Typical Office Procedure

Fig. 10. Flow Process Chart of Watchman's Operations
(Courtesy of A. H. Mogensen)

in the charting of industrial operations. Fig. 9a shows the symbols developed by Piacitelli, and now used in several government offices. Fig. 9b is an example of this application. Both of these appear in a "Guide to Process Charting" prepared by the Civilian Personnel Division of the Office of the Secretary of War. To the basic symbols, shown in Fig. 1, which represent activity or condition, have been added others to represent things, and the therblig symbols (Fig. 14) have been incorporated with these to give more refined delineation to the activity taking place.

MAN TYPE OF FLOW PROCESS CHART.—The same techniques that have been used to follow materials and forms through operations can be applied to following a man through a series of operations and movements performed by him. Their chief field of application is to those jobs which require a man to operate over a considerable area or where the job is not highly repetitive or standardized. Service and maintenance work, laboratory procedure, and much of the work of supervisors and executives can be reduced to charts of this type. Fig. 10 shows a simple application of this chart. Since the charts follow one individual, they take the form of a series of events in a straight line, therefore the standard forms shown previously may be used.

Operation Analysis

BREAKDOWN OF OPERATIONS.—Operation analysis may be defined as the subdivision of an operation into its motion elements so that these may be studied and resolved into methods of least waste. The degree of refinement into which the operation may be subdivided depends upon the nature of the work being done. In the case of an operator running a machine, it may be sufficient to break down the work cycle into the set-up or loading time, running time, and time for clearing the machine, or it may be necessary to break down further the work of loading and clearing the machine into each element of the operation. This breakdown is usually done by visual observation and the times are determined by stop-watch timing. The data are recorded on multiple-activity charts (Fig. 11, 12a, 12b, and 13).

FACTORS IN MAKING THE ANALYSIS.—For an assembly operation it is customary to show the detailed motions performed by both hands. These motions may be determined visually and shown either with or without time. A great deal of what might be called "simple motion study" is carried out by a qualitative analysis of the motions constituting the work cycle without a quantitative time measurement. For such a study an operator's right- and left-hand process chart is used (Figs. 25 and 26).

When the work cycle is very short and the operator's motions are too rapid for the observer to record what is taking place, it is necessary to resort to photographic means to catch the action. This method makes possible the minutest subdivision of motions and their time measurement, called "micromotion study." The graphic means for expressing this subdivision is the simultaneous motion-cycle chart (Fig. 33).

These techniques provide a means for measuring all work, and are

OPERATION SPOOLING 5 YD. X 12" PLASTER DATE DECEMBER 19–
MACHINE SPOOLING MACHINE CHART BY A. W.
OPERATOR GEZA WOLFE PART HOSPITAL PLASTER CHART NO. 2
DEPARTMENT PLASTER FINISHING SHEET NO. 1 OF 1

SUMMARY:

	OLD		NEW
1. TOTAL MAN OPERATING TIME (LEFT SIDE OF CHART)	34	SEC.	48
2. TOTAL MACHINE OPERATING TIME (RIGHT SIDE OF CHART)	16	SEC.	16
3. TOTAL TIME TO PERFORM COMPLETE OPERATION (CYCLE)	50	SEC.	50
4. MACHINE UTILIZATION (#2 DIVIDED BY #3)	32	%	32
5. OPERATOR EFFECTIVENESS (#1 DIVIDED BY #3)	68	%	96

OLD METHOD

MAN		MACHINE
1. PLACE CRINOLINE ON MANDREL 2. PLACE PLASTER ON CRINOLINE 3. DATE STAMP PLASTER 4. START MACHINE	20	BEING SET UP
IDLE		5. SPOOL PLASTER MACHINE AUTOMATICALLY CUTS PLASTER (5 YDS.) AND STOPS
6. CUT CRINOLINE 7. DATE STAMP 8. FOLD CRINOLINE ON ROLL 9. REMOVE ROLL FROM MACHINE 10. PLACE ROLL IN TRUCK	14	BEING CLEARED

NEW METHOD

MAN	MACHINE
1. PLACE CRINOLINE ON MANDREL 2. PLACE PLASTER ON CRINOLINE 3. DATE STAMP PLASTER 4. START MACHINE	BEING SET UP
5. GET METAL CAP AND TUBE FILLED WITH SPOOL OF 5 YD. PLASTER FROM PREVIOUS OPERATION. 6. PLACE CAP ON TUBE 7. PLACE COMPLETE ASSEMBLY IN PACKING CASE. IDLE	5-A. SPOOL PLASTER MACHINE AUTOMATICALLY CUTS PLASTER (5 YDS.) AND STOPS
8. CUT CRINOLINE 9. DATE STAMP 10. FOLD CRINOLINE ON ROLL 11. REMOVE ROLL FROM MACHINE 12. PLACE ROLL IN TUBE	BEING CLEARED

FIG. 11. Analysis of Operator and Single Spooling Machine
(Courtesy of A. Williams)

progressively more expensive to apply as the degree of refinement of measurement increases, therefore the one that should be used is the one that employs measurement merely to that degree which adequately satisfies the conditions of the problem.

MULTIPLE-ACTIVITY CHART.—The multiple-activity chart, also known as the man-and-machine chart, is "a synchronized graphic representation of operations performed simultaneously by two or more men, two or more machines, or any combination of men and machines." The chart may be drawn with the same symbols that appear on the flow chart. These symbols will give a rough picture of the balance of working and idle time for both man and machine which may be sufficient for suggesting the general outline of an improvement. The determination of the precise details of an improvement, however, requires a knowledge of the times taken for each activity of the man and machine. These times may be obtained by stop-watch observation, or by means of motion pictures with a chronometer in the field of the camera. The times for each activity of man and machine are charted on a vertical time scale. By this means the beginning, ending, and duration of each activity are clearly set forth in the proper time relation with every other activity. By a study of these activities with their corresponding time intervals, it is possible to determine whether a more effective utilization of the operator's time or machine time can be achieved by a rearrangement of the work cycle.

Operation of One Machine.—In the accompanying chart (Fig. 11) it is seen that under the old method the man is idle about one-third of the time, and that, during the entire time, the machine is either running or being set up or cleared of work. Since the machine is really not idle at all, the major opportunity for improvement lies in finding work for the man to do during his period of idleness.

Possible Changes in Methods.—There are two alternatives, as will be described, for eliminating this idleness—to give the operator another, similar machine to run, or to find other work for him to do during his idle period. If the operator is assigned a second machine he will be kept busy 100% instead of 68% of the time, and his production will be increased by about 50%. This increase in operator effectiveness is offset by a decrease in machine utilization. In performing this work cycle the operator, after starting one machine, will clear the other machine of its finished roll and set it up with a new one. This takes 34 sec., but the first machine which he had started up will complete its spooling in 16 sec., leaving 18 sec. for idleness before he can return to it and prepare it for running again.

Thus the work cycle for each machine has been increased from 50 sec. to 68 sec. by the addition of 18 sec. of idleness. This change amounts to a reduction of 26.5% in output per machine. In the case of an expensive machine bearing a high burden charge, the increase in the machine expense might be far greater than the savings in direct labor. Also it might be necessary to get all the production possible out of the existing machines, in which case they should not be idle.

By employing the second alternative—giving the operator other work to do during his idle period—it was found that, after some improvements were made, he could combine the succeeding operations—placing

MULTIPLE ACTIVITY PROCESS CHART

METHOD. PRESENT ________ PROPOSED ✓ LOCATION ________

OPERATION *Spooling 12 inch 5 yard Plaster*

DWG. NO. ________ PART NO. ________

DATE CHARTED *May 29—* CHARTED BY *D.B.P.* APPROVED ________

ACTIVITY IDENTIFICATION

NO	MACHINE OR OPERATOR'S NAME	IDENTIFYING NUMBER
1	*Operator No. 1*	
2	*Operator No. 2*	
3	*Spooling Machine No. 1*	
4	*Spooling Machine No. 2*	
5	*Spooling Machine No. 3*	
6		
7		

SUMMARY

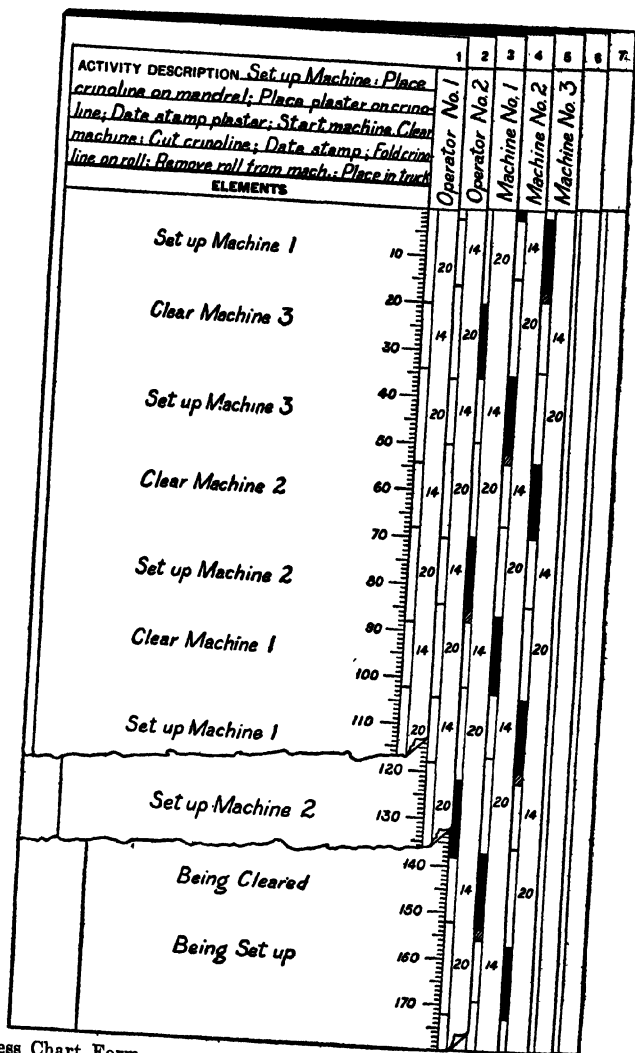
TOTAL YEARLY SAVING IN DOLLARS.

DIRECT LABOR	*2240.00*
MACHINE EXPENSE	*— 40.00*
TOTAL	*2200.00*
INSTALLATION COST OF PROPOSED METHOD	*0.00*
ESTIMATED NET SAVING—FIRST YEAR	*2200.00*

	PRESENT METHOD	PROPOSED METHOD	DIFFERENCE
Number Man — sec. per roll	*50*	*34*	*—16*
Percent of Time Man Works	*68*	*100*	*+32*
Number Machine—sec per roll	*50*	*51*	*+1*
Percent of Time Machines Run	*32*	*31.4*	*—.6*
Percent Increase in Production		*47.*	
Unit Cost: Labor + Mach. Exp.	*1.81¢*	*1.37¢*	*—0.44¢*

TIME SCALE 1 DIVISION = *1 second*

(a) FIG. 12. Multiple Activity

(a) Cover, (b) chart pages. Prepared in pamphlet form to cover cases where one or of individual activities should be brought close together for effective comparison and

Process Chart Form

more workers tend two or a larger group of machines for which the detailed charts (b) readjustment to give maximum productive use of time.

the spool of plaster in a tube, capping the tube, and placing it in the packing case—with his own job by fitting them into his idle period, as shown in the new method of Fig. 11. In this way, the operator's effectiveness has been raised to 96% and the machine is running at its maximum utilization under the conditions of the method employed. This step does not preclude an improved machine which might further shorten the work cycle.

TWO OPERATORS AND THREE MACHINES.—Another solution of the above problem is possible when production from more than one man or machine is desired. A combination of two operators and three machines works out with no operator idleness, and only 2% of machine idleness. An illustration of this arrangement is given in Fig. 12a-b, which is the form of multiple activity process chart developed by the Special Committee of the A.S.M.E. on the Standardization of Therbligs, Process Charts and Their Symbols, consists of seven separate overlapping charts, each depicting the activities of a man or a machine under investigation. With the exception of chart 1, the only visible section of each successive chart is the column at its extreme right edge. These columns carry the colored or sectioned bars which express the activities of the operators and machines. By this arrangement the bars are brought close together for easy study and reference. By turning over each page just as the pages of a book are turned from right to left, the complete descriptions of the activities are revealed.

Horizontal expansion is accomplished by opening a new chart book to chart 1, and laying this new opened chart book under the old so as to leave its fresh series of seven right-hand tabs exposed, thus making fourteen tabs in all. The front cover of the second book is then trimmed, folded around the left-hand of the first book, and pasted to its front cover. This method will provide for seven more activities, and the size of the combined chart will be 8½" x 11". Vertical expansion may be accomplished by pasting extension forms to the bottom of each page and folding them inward to fall within the cover boundaries.

Activities Defined.—

1. "Man working" is a person performing an operation or any part of an operation independently of a machine or of another person. For example, a man working at an assembly operation; also, in a work cycle involving the use of a machine or another man, that part of the man's time during which he is working independently—that is, not setting up, loading, operating, or unloading the machine or working with another man.
2. "Machine running" is defined as the time the machine is operating, performing its work without requiring attention, so that the operator is free for other work.
3. "Combined activity" is that part of a work cycle during which a man is working with a machine or another man. It includes such activity as setting tools, loading and unloading work where this ties up the machine, and the machine running time when it requires the attention of an operator; also the time when two or more men are working in unison. It has been found convenient when analyzing a cycle of man and machine time to differentiate between their times when working independently of each other and when one depends upon the other. The blocks of time representing independent work may be shifted around independently of each other, whereas the

Fig. 13. Study Showing No Gain in Running Two Machines
(Courtesy of A. H. Mogensen)

blocks representing combined activity must not be shifted with reference to each other.

4. "Idleness" is complete inactivity on the part of a man or machine. For the man it is usually during the machine running time when there may be nothing for him to do, and for the machine it is when it is stopped and waiting for the attention of an operator.

Color Code.—There has been a diversity of practice in the code used to represent the activities on the multiple activity process chart, and the code has not yet been standardized by the Committee. The code used in Fig. 12a-b is the selection of the author, and is as follows: "Man working" and "machine running," both black; "combined activity," white; and "idleness," red or cross-sectioned.

On the other hand, Fig. 13 is a chart of a man operating two machines and shows that nothing is gained in operator effectiveness thereby and that machine utilization is very low. Only when the running time of the machine does not require operator attention can additional machines or other work be profitably given to the operator.

Use of Charts with Groups of Workers.—This form of chart can be used most effectively in showing the work of a group of people whether with or without machines when the work of each individual must be coordinated with that of the others with respect to time. It serves as a means of making a graphical record of an intricate set of relationships that can be more easily visualized and studied for improvement.

Elements of Motion

ORIGIN OF THERBLIGS.—Most manual work can be performed with a relatively few elementary motions that are repeated over and over again. The Gilbreths divided work into 17 classifications. Most of these are motions of the hands, some are the absence of motion, and others are mental reactions. To these they gave the name "therblig" which is coined from the letters of their name, reversed. The word is represented by synonyms such as basic divisions of accomplishment, or fundamental motions, or Gilbreth basic elements. They serve as useful categories for the classification of similar types of motions for study and refinement. The therbligs with their symbols in both sign and letter form and their color designations are shown in Fig. 14.

EXPLANATION OF THE THERBLIGS.—From the many definitions and interpretations of these therbligs the following explanations have been developed to clarify the meanings of the respective terms:

1. **"Search"** refers to a movement of the eyes in looking, or to the hands in groping for an object. When performed by the eyes it precedes the movement of the hands, but when the eyes are not employed search depends upon the sense of touch which involves movement of the hands.
2. **"Find"** is a hesitation following search, usually involving a mental reaction caused by unfamiliarity with the work.
3. **"Select"** refers to the choice of one or more definite objects from among several, usually similar objects. It may entail the removal or separation of one article from another to pick up one of them. It follows the therblig "transport empty." When search has been

performed by a groping of the hands followed by a selection of the object, it is difficult to distinguish where one ends and the other begins. It is the usual practice to combine these factors and call them "select."

4. "**Grasp**" is the act of acquiring control of an object by the hand. It begins the instant any part of the hand touches the object and ends when the control necessary for performing the next therblig has been established. It may be only a finger contact preparatory to sliding something, or it may involve the fingers as in picking up, or the whole hand as in grasping a tool.
5. "**Transport Loaded**" is the carrying or sliding of an object from one place to another. It usually follows "grasp" and begins the instant the hand starts to move. It may follow "disassemble" and in this case it begins the instant that the object has been separated from the one that held it and begins its free and unconstrained movement toward a new location. It ends when the object has reached that location and its free movement has been arrested. It is usually followed by "position."
6. "**Position**" consists of manipulating an object to bring it into alignment with another object. It may be performed before or during "transport loaded," and it nearly always occurs before and sometimes after the therbligs "assemble" and "use."
7. "**Assemble**" consists of placing a positioned object in or on another object from which it is later removed, such as a part in a fixture, or a wrench on a nut. It follows "position" and begins as the hand starts to move the object into its place. Sometimes the boundary between these two is difficult to determine especially when "assemble" is very brief. In such cases the two are thrown together as "position and assemble," or just "position" if that is the dominant therblig. It ends when the hand starts to release the part or to use the tool. "Assemble" belongs to the "get ready" portion of the work cycle.
8. "**Use**" consists of placing a positioned object in or on another object with which it forms an integral part, or in manipulating a tool or device in a manner for which it was intended. It always advances the operation toward the ultimate objective. It is the "do" portion of the work cycle. All other therbligs are preparatory or supplementary to it and are subject to possible elimination. Only "use" is indispensable and therefore it is the most important therblig. It embraces an almost infinite variety of cases. When it refers to placing two parts together, as in an assembly, it follows "position" and may be difficult to distinguish from it. In such cases the two are combined into "position and use" or just "position" if that is the dominant therblig. When "use" refers to the manipulation of a tool such as a wrench or screwdriver, it follows the assembly of the tool to the nut or screw, and consists only of the actual functioning of the tool.

Some authorities assign the therblig "assemble" to the placing together of two integral parts of a whole. This step seems natural because the act satisfies the definition of the word. However, to do so would place the therblig "assemble" in both classifications "get ready" and "do," which seems inconsistent. When analyzing a therblig motion-cycle chart, it is convenient to have all the "do" or indispensable acts represented by one therblig "use," so that attention may be focused on all the others and consideration given to their possible elimination. For these reasons it seems better to have "use" include an assembly which advances the operation, and to reserve "assemble" for a temporary assembly which does not advance the work, such as putting a part into a fixture.

Therblig	Therblig Symbol		Explanation-suggested by	Color
Search	Sh.		Eye turned as if searching	Black
Find	F.		Eye straight as if fixed on object	Gray
Select	St.		Reaching for object	Gray, light
Grasp	G.		Hand open for grasping object	Lake red
Transport loaded	T.L.		A hand with something in it	Green
Position	P.		Object being placed by hand	Blue
Assemble	A.		Several things put together	Violet, heavy
Use	U.		Word "Use"	Purple
Disassemble	D.A.		One part of an assembly removed	Violet, light
Inspect	I.		Magnifying lens	Burnt ochre
Pre-position	P.P.		A nine-pin which is set up in a bowling alley	Sky-blue
Release load	R.L.		Dropping content out of hand	Carmine red
Transport empty	T.E.		Empty hand	Olive green
Rest for overcoming fatigue	R.		Man seated as if resting	Orange
Unavoidable delay	U.D.		Man bumping his nose, unintentionally	Yellow ochre
Avoidable delay	A.D.		Man lying down on job voluntarily	Lemon yellow
Plan	Pn.		Man with his fingers at his brow thinking	Brown
Hold	H.		Magnet holding iron bar	Gold ochre

FIG. 14. Therblig Symbols

Dixon Pencil Number Round p'l Heavy lead	Eagle Pencil Number	Dixon Crayon Hex. pencil Thinex lead	Faber	American	Blaisdell
331	747	379	6629	116 Black	152T
399	747½	352½	6619	116 Black lightly	140T
399 Lightly	734½	352½	6619 Lightly	116 Black lightly	139T
369	745 Carmine	321½	6616 Madder red	116 Red	162T Crimson
375	738 Grass Green	354	6628 Dark green	116 Green	153T
376	741 Indigo blue	350	6625 Dark blue	116 Indigo	151T
377	742	323	6624	116 Violet	137T
396	742½ Lavender	323½	6614		138T
377	742	323	6624	116 Violet	137T
398	745½ Terra cotta	335½	6613 Terra cotta		144T Sienna brown
394	740½	320	6605	116 Light blue	149T Azure blue
370	744 Scarlet	321	6626 Scarlet		161T Red
391	739½	325	6648	116 Light green	148T
372	737	324	6622	116 Orange	157T
373	736	324½	6607 Dark yellow	116 Vermilion	154T Yellow
374	735	353½	6617		154½T
378	746 Sienna brown	343	6623	116 Brown	155T Dark brown
388	736½ Orange ochre	388	6633		145T Blue print red

and Color Designations

9. "**Disassemble**" consists of removing one object from another object with which it had been "assembled." It may be the removal of an assembly from a fixture or of a wrench from a nut. It begins when the hand starts to remove the object and ends when the hand has completely separated it from the object with which it has joined.
10. "**Inspect**" consists of examining an object for its conformance to a standard of quality. It may employ any one of the senses and occur simultaneously with other therbligs.
11. "**Pre-position**" consists of placing an object in such a position that it may be grasped in the position in which it is to be used. It usually refers to placing a tool in a holder so that it may be grasped and used without further turning or twisting.
12. "**Release Load**" consists of letting go the object held in the hand by laying it down, dropping it, or throwing it. This therblig begins when the hand starts to release control of the object and ends when the object is entirely free from the hand. It is the opposite of "grasp."
13. "**Transport Empty**" is the movement of the empty hand from one location to another. It usually follows "release load" and begins the instant the hand starts to move and ends when the fingers or any part of the hand touch the object being grasped.
14. "**Rest for Overcoming Fatigue**" is idle time provided to allow the worker to recover from the fatigue caused by his work. It seldom appears as a therblig within the pattern of a work cycle but occurs as a rest period between periods of work.
15. "**Unavoidable Delay**" is idle time caused by an interruption in the operation, or by a sequence of motions which prevents one hand from working while the other one is busy.
16. "**Avoidable Delay**" is any idle time for which the operator is responsible and which he may avoid, if he wishes, without changing the method of work.
17. "**Plan**" is a mental process which determines a following action. It may occur while hands are idle waiting for the mental decision, or it may occur while hands are performing preceding therbligs, in which case there is no idle time.
18. "**Hold**" consists of retaining an object in the hand in a fixed position without moving it. It occurs most often where one hand is used as a vise to hold work. It was originally considered as a form of "grasp" but present-day usage recognizes it as a separate therblig.

The Committee on Standardization of Therbligs, Process Charts and Their Symbols is revising the definitions and symbols for the therbligs and when its report is revised it will become the standard.

THERBLIG DATA.—The following data are taken from the investigations of Professor Ralph M. Barnes at the University of Iowa, published in a series of bulletins by that university, and from his book Motion and Time Study. The time values in the tables should be considered not as standard data from which to compile standard cycle times, but instead relatively as changes in time which might be expected when performing therbligs under varying conditions. In this way the optimum conditions are determined for performing therbligs in the shortest time.

Study of Grasp.—There are two types of grasp commonly used: (1) pressure grasp as in grasping by pinching a thin or small object lying flat on a table; and (2) hook grasp as in grasping an object that is raised or positioned so that the fingers are able to reach around it. Fig.

15 shows the time required for a hook grasp and a pressure grasp for a piece of soft steel wire .045 in. in diameter and 1¼ in. in length when lying at random on a table top but not tangled, and when positioned vertically in holes, and when placed horizontally in grooves cut away so that thumb and forefinger may reach around the wire.

Position of Material	Time in Minutes Required to Grasp			
	Average	Mode	Minimum	Maximum
At random on table top (pressure grasp)	.00558	.0050	.0040	.0110
Vertical in holes (hook grasp)..........	.00279	.0025	.0020	.0055
Horizontal in grooves (hook grasp)......	.00225	.0020	.0020	.0030

FIG. 15. Time for Grasping Sample of Wire

Time required to grasp flat objects (washers) of varying thickness from a flat surface, transport them 5 in., and position them on a similar flat surface, using both hook and pressure grasps, is shown in Fig. 16. Washers were metal, all ½ in. in diameter with a ⅛-in. hole in the center, and varying in thickness from 1/32 to ½ in.

The hook grasp was performed by placing the forefinger on top of the washer and drawing it from the edge of the surface, where it had been positioned, onto the thumb. This is also called a lip grasp. The pressure grasp was made by placing the thumb and forefinger down and around the washer and pinching it. When the washers are thin, under ⅛ in., this grasp is difficult and takes about twice as long as the lip grasp, but when the washer is thick enough for the fingers to secure it by pressure on the vertical cylindrical walls, this grasp may be done in about one-half of the time of the lip grasp. It really becomes a hook grasp, fingers around the object, and becomes faster than the lip grasp because in the latter the washer has to be slid before the fingers can reach around it. It is noted that the transport loaded and positioning of the washer also becomes shorter after a pressure grasp for washers

Factor *			Thickness in Inches			
			1/32	1/8	1/4	1/2
Grasp	Time in minutes	Hook	.00315	.00314	.00340	.00323
		Pressure	.00629	.00308	.00233	.00158
	Time in per cent (Shortest time found in either grasp = 100%)	Hook	200	199	215	204
		Pressure	397	195	147	100
Transport Loaded and Position	Time in minutes	Hook	.00465	.00510	.00561	.00677
		Pressure	.00628	.00571	.00514	.00473
	Time in per cent (Shortest time found in either grasp = 100%)	Hook	100	110	121	146
		Pressure	135	123	111	102

* Averages of median time values for five male and five female operators are shown.

FIG. 16. Averages of Median Time Values in Grasping Washers of Different Thicknesses

over ⅛ in. thick, therefore this type of grasp is indicated for washers over ⅛ in. thick while the lip grasp is better for thinner washers.

The time required to grasp and transport a small object by carrying and by sliding it through a short distance is shown in Fig. 17.

THERBLIG	TIME IN MINUTES					
	Rubber Washer		Steel Washer		Lock Washer	
	Carry	Slide	Carry	Slide	Carry	Slide
Grasp	.00960	.00033	.00895	.00031	.00750	.00038
Transport Loaded	.00690	.00640	.00530	.00896	.00855	.00711
Total	.01650	.00673	.01425	.00927	.01605	.00749

FIG. 17. Time for Grasping and Transporting Different Kinds of Washers

There is not much difference in the transport loaded time by carrying or sliding, but the grasp and transport loaded took about twice as long when the washers were carried than when they were slid.

Time to select and grasp small machine screws and nuts from three types of bins is shown in Fig. 18, taken, with the three following charts, from Barnes, Motion and Time Study.* The times are averages for screw and nut sizes varying from No. 2 to No. 12. The shortest grasp is made with the bin with tray for both nuts and screws; however, the screws take 19% longer to grasp than the nuts. This type of bin permits using a lip grasp which is especially effective for thin flat objects. Grasping nuts from either the hopper-type bin or rectangular bin takes about the same length of time, but this is over 60% longer than from the bin with tray. Grasping screws from the rectangular bin takes 17% longer and from the hopper-type bin 26% longer than from the bin with tray. Screws are grasped more easily than nuts from both the hopper-type and rectangular bins, which is just the opposite from the case of the bin with tray where nuts are more easily grasped than screws. These results indicate that for grasping nuts the bin with tray has a substantial advantage but that for grasping screws this advantage is only moderate. In the over-all cycle, which includes disposing the screws and nuts through a hole 5 in. in front of the trays, the bin with tray gives the shortest times for both screws and nuts.

Position.—The time required to position and insert pins in bushings with beveled holes is given in Figs. 19a and 19b. The operation consisted of grasping a ¼-in. brass pin 1¼ in. long from a magazine, carrying it through a distance of 5 in., then positioning and inserting it in the hole in the bushing, withdrawing the pin, and disposing of it in a tray. This was done for bushings with bevels ranging from 45° to 0°, and with two sizes of holes having a clearance between pin and hole of .002 in. and .010 in. The minimum time to position was with the 45° bevel, and this tended to increase as the bevel decreased, rising sharply with zero bevel. The time for transport loaded preceding position appears to behave in the same general way, while the time for assemble and disassemble following position gets less as the degree of bevel decreases, reaching the most rapid rate of decrease as the degree of bevel reaches zero.

* John Wiley & Sons.

(Photograph goes here)		Hopper Type Bin		Rectangular Bin		Bin with Tray	
		Nuts	Screws	Nuts	Screws	Nuts	Screws
SELECT AND GRASP Nut or screw from bin	Time in Minutes	**0.00629**	0.00586	**0.00653**	0.00541	**0.00390**	0 00465
	Time in Per Cent (Shortest Time = 100%)	**161**	126	**168**	117	**100**	100
TRANSPORT LOADED Carry nut or screw through distance of 5 inches	Time in Minutes	**0.00193**	0.00339	**0.00236**	0 00418	**0.00205**	0.00318
	Time in Per Cent (Shortest Time = 100%)	**100**	106	**123**	132	**106**	100
RELEASE LOAD Drop nut into 1-inch hole in table top	Time in Minutes	**0.00404**	0.00397	**0.00360**	0 00350	**0.00368**	0 00385
	Time in Per Cent (Shortest Time = 100%)	**112**	113	**100**	100	**102**	110
TRANSPORT EMPTY Move hand to bin for nut.	Time in Minutes	**0.00152**	0 00245	**0.00233**	0 00305	**0.00198**	0 00258
	Time in Per Cent (Shortest Time = 100%)	**100**	100	**154**	125	**131**	106
TOTAL CYCLE (G. + T. L. + R. L. + T. E.)	Time in Minutes	**0.01377**	0 01567	**0.01480**	0 01614	**0.01160**	0 01428
	Time in Per Cent (Shortest Time = 100%)	**119**	110	**128**	113	**100**	100

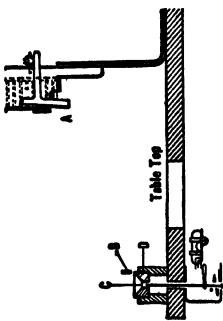
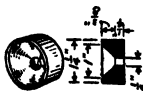
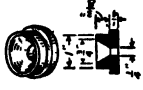
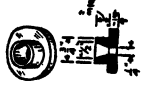
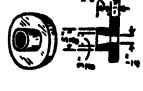
FIG. 18. Time to Grasp, Carry and Dispose of Nuts and Machine Screws
(Barnes, Motion and Time Study)

		1		2		3		4		5	
		Clearance Between the Pin and the Hole in the Bushing in Inches									
		0.002	0 010	**0.002**	0 010	**0.002**	0.010	**0.002**	0.010	**0.002**	0 010
TRANSPORT LOADED Carry pin from magazine at *A* (see figure above) through distance of 5 inches to edge of bushing at *B*.	Time in Minutes	**0.00519**	0 00564	**0.00506**	0 00531	**0.00579**	0 00542	**0.00616**	0 00592	**0.00640**	0 00716
	Time in Per Cent (Shortest Time = 100%)	**102**	106	**100**	100	**114**	102	**121**	111	**126**	135
POSITION Place pin in hole *C* of bushing *D*.	Time in Minutes	**0.00469**	0 00271	**0.00544**	0 00285	**0.00483**	0 00386	**0.00492**	0.00377	**0.00809**	0.00672
	Time in Per Cent (Shortest Time = 100%)	**100**	100	**116**	106	**103**	143	**105**	139	**173**	248
TRANSPORT LOADED AND POSITION	Time in Minutes	**0.00988**	0 00835	**0 01050**	0 00816	**0.01062**	0.00928	**0.01108**	0.00969	**0.01449**	0 01388
	Time in Per Cent (Shortest Time = 100%)	**100**	102	**106**	100	**108**	114	**112**	119	**147**	170
ASSEMBLE AND DISASSEMBLE Insert pin down into hole *C* and withdraw pin.	Time in Minutes	**0.00316**	0 00333	**0.00306**	0 00321	**0.00298**	0 00324	**0.00293**	0.00283	**0.00232**	0.00201
	Time in Per Cent (Shortest Time = 100%)	**142**	165	**138**	160	**135**	160	**132**	141	**100**	100
TOTAL OF TRANSPORT LOADED, POSITION, ASSEMBLE, AND DISASSEMBLE	Time in Minutes	**0.01304**	0 01168	**0.01356**	0 01138	**0.01360**	0 01250	**0.01400**	0.01253	**0.01670**	0.01588
	Time in Per Cent (Shortest Time = 100%)	**100**	103	**104**	100	**105**	110	**107**	110	**128**	140

FIG. 19a. Time to Position Pins in Bushings
(Barnes, Motion and Time Study)

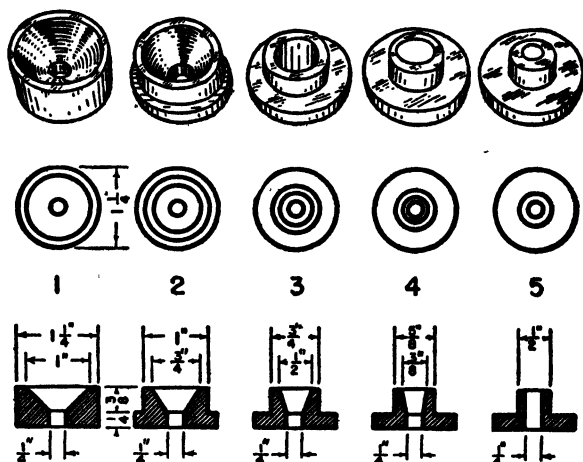



FIG. 19b. Steel Bushings. Two sets, each of five bushings, were used for the study of Fig. 19a. For part A, the diameter of the hole in the bushing was .250 in.; for part B, the diameter of the hole in the bushing was .258 in.
(Barnes, Motion and Time Study)

It is apparent that these therbligs are interrelated, hence standard times for therbligs may not exist as independent values but only as variables to be determined by the influence of other therbligs in the cycle. It will also be noted in this study that with zero bevel, there is small difference in the total time between the bushings with .002-in. clearance and .010-in. clearance.

The results of positioning bars on pins are shown in Fig. 20. The operation consisted of grasping a flat bar ⅛ in. thick, ⅝ in. wide and 3 in. long, removing it from two pins near the front edge of the table, carrying it through a distance of 5 in., positioning it on two machined pins, and dropping it over the pins. This was done for two conditions of clearance between the pin and the hole in the bar, one where it was .003 in. and the other with .011 in. The results indicate the advantage of pins with rounded ends and of unequal height if the conditions of the assembly would permit such a design. If not, the advantage of using guides with square-ended pins of equal height is shown as second best.

Principles of Motion Economy

ORIGIN OF THE PRINCIPLES.—Principles of motion economy were first set forth by the Gilbreths (S.I.E. Bul., vol. 5) and added to by others, notably Barnes (Motion and Time Study). Not all of

Table Top

A B C

		1 Pins of equal height with square ends. Guides at left end and back.		2 Pins of equal height with square ends.		3 Pins of unequal height with square ends.		4 Pins of equal height with round ends.		5 Threaded pins of equal height with square ends.	
		Clearance Between the Pin and the Hole in the Bar in Inches									
		0.003	0 011	**0.003**	0 011	**0.003**	0 011	**0.003**	0 011	**0.003**	0 011
TRANSPORT LOADED Carry bar from supply at *A* (see figure above) to the pin set at *B*.	Time in Minutes	**0.00679**	0 00587	**0.00657**	0.00557	**0.00645**	0 00585	**0.00600**	0 00567	**0.00554**	0 00590
	Time in Per Cent (Shortest Time = .100%)	**113**	105	**109**	100	**108**	105	**100**	102	**109**	106
POSITION Place bar on pin set at *B*.	Time in Minutes	**0.00452**	0 00302	**0.00706**	0 00502	**0.00552**	0 00410	**0.00275**	0 00198	**0.00785**	0 00614
	Time in Per Cent (Shortest Time = 100%)	**164**	152	**256**	253	**201**	207	**100**	100	**286**	309
TRANSPORT LOADED AND POSITION	Time in Minutes	**0 01131**	0 00889	**0 01363**	0 01059	**0.01197**	0 00995	**0 00875**	0 00765	**0 01439**	0 01204
	Time in Per Cent (Shortest Time = 100%)	**129**	116	**156**	138	**137**	130	**100**	100	**164**	157

FIG. 20. Time to Position Bars on Pins
(Barnes, Motion and Time Study)

these principles are applicable to every work cycle, but in any specific case the adherence to those principles which are found to apply is imperative for securing the maximum economy in work performance.

THREE SUBDIVISIONS OF THE PRINCIPLES.—These principles fall under three subdivisions, with respect to use of the human body, arrangement and condition of the workplace, and design of tools and equipment, and supplementary rules for analysis procedure:

Use of the Human Body.

1. Both hands should begin and end their therbligs at the same instant.
2. Both hands should not be idle at the same instant except during rest periods.
3. Motions of arms should be in symmetrical and usually in opposite directions, and should be made simultaneously.
4. Motions should be confined to lowest possible classifications in order to reduce fatigue. Listed in the order of giving least fatigue and maximum economy these are:
   - First: Finger motions.
   - Second: Finger and wrist motions.
   - Third: Finger, wrist and lowerarm motions.
   - Fourth: Finger, wrist, lowerarm and upperarm motions.
   - Fifth: Finger, wrist, lowerarm, upperarm, and body motions.
5. Momentum should be employed to assist the worker where possible, and it should be reduced to a minimum where it must be checked by muscular effort.
6. Continuous curved motions are preferable to straight-line motions involving sudden and sharp changes in direction.
7. Ballistic movements are faster, easier, and more accurate than restricted or "controlled" movements.
8. Sequence of motions should be arranged to build rhythm and automaticity into the operation.
9. Hands should be relieved of all work that can be done by the feet or other parts of the body.

Arrangement and Conditions of the Workplace.

1. Definite and fixed stations should be provided for all tools and materials to permit habit formation and development of automaticity.
2. Tools and materials should be pre-positioned wherever possible to reduce the search, find and select therbligs.
3. Gravity feed bins should be used to deliver the material close to the point of use and at a height which will eliminate any lifting or change in direction in carrying the material from bin to point of use.
4. All material and tools should be located within the normal grasp area and as close in front of the operator as possible.
5. Tools and materials should be located to permit the best sequence of therbligs. The part required at the beginning of the cycle should be next to the point of release of the finished piece from the former cycle.
6. Use "drop delivery" or ejectors whereby the operator may deliver the finished article, by releasing it in the position in which it was completed, without moving his hands to dispose of it.

7. The height of the workplace and chair should preferably be arranged so that alternate sitting and standing at work are made easily possible.
8. A chair of the type to permit correct posture should be provided for every operator.
9. Illumination of proper intensity and quality should be provided as essential for seeing.
10. Where possible, the color of the workplace should be selected so as to aid visual perception and reduce eye fatigue.
11. Proper ventilation by air which is conditioned for temperature and humidity should be provided for comfort and health.

Design of Tools and Equipment.

1. Two or more tools should be combined in one tool wherever possible.
2. Machines that are finger operated should be designed to distribute the load among the fingers in accordance with their capacity to perform work.
3. Handles, such as those used on cranks and large screwdrivers where considerable force is to be exerted, should be designed so that as much of the surface of the hand as possible comes in contact with the handle. This gives maximum bearing area and minimum unit bearing pressure.
4. Levers, crossbars, and handwheels should be located in such positions that the operator can manipulate them with the least change in body position and with the greatest mechanical advantage.

Supplementary Rules for Analysis Procedure.

1. Hesitation should be analyzed and studied and its causes accounted for and if possible eliminated.
2. Shortest time demonstrated in one part of a study should be used as a mark to attain, and reason for other times required in other parts of the study should be known.
3. Number of therbligs required to do work should be counted: the best way is almost always a sequence of the fewest therbligs.
4. The best sequence of therbligs in any one kind of work is useful as suggesting the best sequence in other kinds of work.
5. Every instance where delay occurs suggests the advisability of providing some optional work that will permit utilizing the time of delay, or of making a fatigue study of the interval.
6. Variations of time required for any single therblig should be arrayed and causes recorded.
7. Lateness of various parts of the anatomy as compared with other portions should be recorded.

ONE- AND TWO-HANDED WORK.—The time to perform work with one hand and with both hands working simultaneously is shown in Fig. 21. Machine screw nuts, sizes 2 and 8, were grasped from two types of bins, carried 5 in. and deposited in a hole. When both hands grasped simultaneously it took 54% longer than when the right hand grasped alone from bin with tray and 81% longer from rectangular bin. The over-all cycle took 31% longer when both hands worked simultaneously with bin with tray and 42% longer with rectangular bin than when the right hand worked alone. It must be remembered that two units of work are accomplished when both hands work together so the net result is a unit of work finished in 65% to 70% of the time taken by one hand.

(Photograph goes here)		Right Hand Working Alone		Left Hand Working Alone		Both Hands Working Together	
		Rectangular Bin	Bin with Tray	Rectangular Bin	Bin with Tray	Rectangular Bin	Bin with Tray
SELECT AND GRASP Nut from bin	Time in Minutes	0.00723	0.00438	0 00822	0 00520	0 01307	0 00674
	Time in Per Cent (Shortest Time = 100%)	100	100	114	118	181	154
TRANSPORT LOADED Carry nut through distance of 5 inches	Time in Minutes	0.00292	0.00235	0.00347	0 00234	0 00380	0.00270
	Time in Per Cent (Shortest Time = 100%)	100	100	119	100	130	115
RELEASE LOAD Drop nut into 1-inch hole in table top	Time in Minutes	0 00403	0.00403	0 00380	0.00453	0 00463	0.00500
	Time in Per Cent (Shortest Time = 100%)	106	100	100	112	122	124
TRANSPORT EMPTY Move hand to bin for nut.	Time in Minutes	0 00314	0 00277	0 00282	0 00304	0 00308	0 00337
	Time in Per Cent (Shortest Time = 100%)	111	100	100	110	110	122
TOTAL CYCLE	Time in Minutes	0 01730	0 01351	0 01832	0 01510	0 02459	0.01778
	Time in Per Cent (Shortest Time = 100%)	100	100	100	112	142	131

FIG. 21. Study of One- and Two-Handed Handling of Machine Screw Nuts
(Barnes, Motion and Time Study)

A study was made at New York University by Batho and deVries in one- and two-handed work for a cycle consisting of grasping a washer pre-positioned on a rod, carrying it a distance of 5 in. from the side to the center, and positioning and releasing it over a post with which it had a .010-in. clearance, then returning for the next washer. Fig. 22 shows the results of this study.

Factor		Right Hand Working Alone	Left Hand Working Alone	Both Hands Working Together
Grasp and remove washer from rod, carry 5 in., position and release over post, return to rod.	Time in minutes Time in per cent	.028 100	.034 121	.038 136

Fig. 22. One- and Two-Handed Moving of Washers

The dominant element in this cycle is positioning the washer over the post, whereas in the previous study it is grasping the nuts. It is significant that the results of these two studies for both hands as compared with the right hand alone are very similar. It would appear that ordinary assembly work can be done with both hands working simultaneously on two units in about 30% to 40% longer time than when the right hand works alone on one unit.

INFLUENCE OF VISUAL CONTROL.—An important factor in such work is the **degree to which the eyes are employed** in controlling the simultaneous movement of the two hands. M. E. Mundel, in a study made at the University of Iowa, found that when visual direction is required to perform a task such as moving the hands 10 in. and positioning two pins in two holes, the optimum paths lie along the lines drawn at 90° with the front edge of the workplace. This brings the hands close together in parallel paths so that the work they have to perform at the end of their transport will be within control of the eyes without shifting eye direction. When the hands are used to make motions without conscious direction and without a task to perform at the end of the transport, it was found that the **optimum paths for the two hands** make angles of 60° with the front edge of the workplace.

These findings indicate that the best location for parts is directly in front of the operator in areas within lines drawn from a point on the edge of the table in front of the operator and making 60° with the edge of the table. This layout gives an included angle of 60° between the lines. In order to locate all parts within this area, it may be necessary to use double- and triple-deck hoppers and bins. This method is better than using a single tier of hoppers and trays which are strung out over a wide area to the right and left of the operator.

WORKING AREA.—The working area is divided into normal and maximum zones. The normal zone for each hand is that area confined within the arc described by each hand when it makes a sweep across

the workplace and pivots about the elbow with the arms hanging loosely at the sides so that the forearm only is extended. Work confined within this area may be performed with motions of the third order, involving only fingers, wrists, and forearm. This is the preferred area within which it is most desirable to locate all parts and tools. The area common to both arcs is the proper location for a fixture where both hands are employed simultaneously, as shown by studies of J. A. Piacitelli.

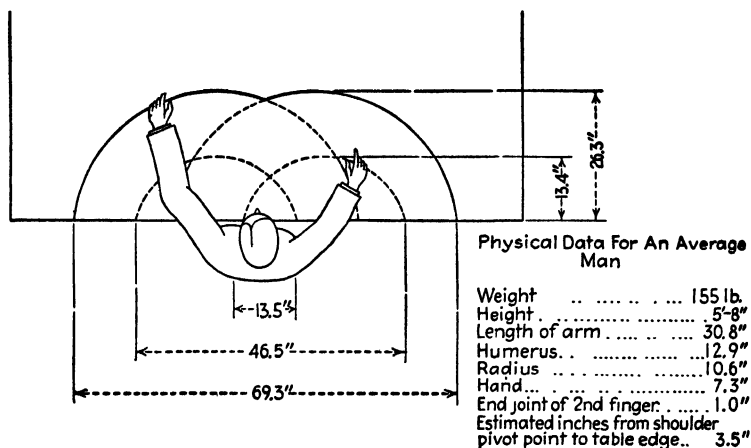



FIG. 23. Normal Working Areas for Arms and Hands
(Courtesy of A. H. Mogensen)

The **maximum zone for each hand** is determined by the arcs described by the hands making sweeps with the arms extended from the shoulders, thus employing the upper arm or fourth class motions. Fig. 23 shows these areas for the horizontal working plane. The dimensions given are average for men, and are about 10% less for women.

The bins holding piece parts are arranged along these arcs, preferably the inner ones if there is room, which makes the so-called "circular" workplace. The two arcs are merged into one forming a slightly flattened semicircle.

Another form of workplace designed by E. H. Schaeffer, employs **soft rubber arm-rests** which pivot and wabble to allow the arms freedom of motion while in contact with the rests. The arcs described by the hands with the forearm pivoting on the rests have shorter radii, and hence these cannot be merged into one flattened semicircle but each must retain its own identity for the location of the piece parts. Fig. 24 shows this arrangement, which has proved very efficient and fatigue-reducing for work of a limited size that can be fitted into the reduced area.

FIG. 24. Interchangeable Table Top for One- and Two-Handed Work

Operator Right- and Left-Hand Process Chart

ANALYSIS OF AN OPERATION.—It was stated earlier in this Section that operation analysis or the study of the details of motions employed by an operator in performing a job should not be made until analysis of the entire process had first been carried out. This analysis involved answering the following three questions of every operation and transportation in the process: (1) Can it be eliminated? (2) Can it be combined with some other operation? (3) Can its sequence be changed? Only then are we ready to ask the final question: (4) Can it be simplified? The answer to this latter question is found through a simple motion study or micromotion study of the operator. These studies are made by means of an operator process chart which is "a synchronized graphic representation of the activities of the right and left hands of the operator while performing an operation and may also include the activities of other body members." A simple motion study consists of an analysis by visual means of the motions made by each hand in performing a cycle of work, and the ultimate improvement of the method through elimination of unnecessary motions, and the combination, change in sequence, and simplification of the remaining motions.

CONSTRUCTING THE RIGHT- AND LEFT-HAND CHART.—The instrument used in making such an analysis is an operator process chart of the right- and left-hand type on which are recorded the motions made by each hand. It is better to concentrate attention on one hand at a time, and list the motions for one hand before doing the other one. The same symbols are used as found on the flow process chart—a circle denotes an operation and a halfsquare-semicircle or a small circle (previous practice) denotes a transportation. An operation may consist of pick up, position with fixture or part, place in fixture or other part, clamp fixture, use tool, wrench, or screwdriver, remove from fixture, release. The transportations are the motions of the hands from one place to another. The symbols are placed in sequence and numbered in order of their occurrence from top to bottom. Motions of the right and left hands occurring at the same time should have their symbols placed opposite each other on the **same horizontal level.** Gaps between symbols are connected by vertical lines.

Identification of Locations on the Workplace.—The chart should contain a suitable heading giving information necessary for identification, and a layout of the workplace preferably placed directly under the heading and above the body of the chart. The location of piece parts in their hoppers or trays is best identified by symbols, as in Figs. 25 and 26, rather than writing the names of the parts in the rectangle representing the tray. There is usually not room to write in the names and when there are many parts it is too confusing to locate them in this way. A system of letters, L-left, R-right, and C-center, with numbered suffixes, makes locations easy to find. When the legend opposite a transport reads L3, for example, as in Fig. 26, the location of that place is readily found and the key gives quick reference to the part, although the name of the part is usually contained in the next operation

OPERATOR CHART

OPERATION MOUNTING STUD FOR RECORDERS - ASSEMBLE DATE JANUARY 19—
DEPARTMENT "B" SHOP CHART BY A.W.
OPERATOR M. SMITH PART NO. P.I. 159 CHART NO. 3
REMARKS STUDS ASSEMBLED 1 AT A TIME SHEET NO. 1 OF 1

OLD METHOD

WORKPLACE LAYOUT

#1. TRAY - STUDS
#2. TRAY - WASHERS
#3. TRAY - NUTS
#4. TRAY - FINISHED ASSEMBLIES

CHART SYMBOLS
OPERATIONS
TRANSPORTATIONS

LEFT HAND			RIGHT HAND
STUD TO WORKING POINT	1	1	HAND TO TRAY #2
		2	PICK UP WASHER
		3	WASHER TO STUD
		4	ASSEMBLE WASHER TO STUD
HOLD STUD	2	5	HAND TO TRAY #3
		6	PICK UP NUT
		7	NUT TO STUD
		8	ASSEMBLE NUT TO STUD
REVERSE STUD	3	9	HAND TO TRAY #3
		10	PICK UP SECOND NUT
HOLD STUD	4	11	NUT TO STUD
		12	ASSEMBLE SECOND NUT TO STUD
RELEASE STUD	5	13	GRASP FINISHED ASSEMBLY
HAND TO TRAY #1	6	14	FINISHED ASSEMBLY TO TRAY #4
PICK UP STUD	7	15	DROP FINISHED ASSEMBLY IN TRAY #4
		16	HAND TO WORKING POINT

REPEAT CYCLE

Fig. 25. Operator Right- and Left-Hand Process Chart—Mounting Studs —Original Method

OPERATOR CHART

OPERATION: MOUNTING STUD FOR RECORDERS – ASSEMBLE DATE: JANUARY 19–
DEPARTMENT: "B" SHOP CHART BY: A. W.
OPERATOR: M. SMITH PART: NO. P.I. 159 CHART NO.: 4.
REMARKS: MATERIAL TO BE REC'D IN TRAYS. WORK IS NOT TO BE STARTED UNLESS ALL MATERIAL IS COMPLETE. STUDS ASSEMBLED 2 AT A TIME. SHEET NO.: 1 OF 1

N E W METHOD

WORKPLACE LAYOUT

L-1 = STUDS (C-37)
L-2 = WASHERS (C-47)
L-3 = NUTS (3/8" x 27)

TOTE BOX FOR FINISHED ASSEMBLIES

L-1 L-3 L-2 JIG R-3 R-1 R-2

R-1 = STUDS (C-37)
R-2 = WASHERS (C-47)
R-3 = NUTS (3/8" x 27)

CHART SYMBOLS

◯ OPERATIONS
○ TRANSPORTATIONS

LEFT HAND			RIGHT HAND
HAND TO L-1	1	1	HAND TO R-1
PICK UP STUD	2	2	PICK UP STUD
STUD TO JIG	3	3	STUD TO JIG
ASSEMBLE STUD TO JIG	4	4	ASSEMBLE STUD TO JIG
HAND TO L-2	5	5	HAND TO R-2
PICK UP WASHER	6	6	PICK UP WASHER
WASHER TO STUD	7	7	WASHER TO STUD
ASSEMBLE WASHER TO STUD	8	8	ASSEMBLE WASHER TO STUD
HAND TO L-3	9	9	HAND TO R-3
PICK UP TWO NUTS	10	10	PICK UP TWO NUTS
NUTS TO STUD	11	11	NUTS TO STUD
ASSEMBLE NUT TO 1ST STUD	12	12	ASSEMBLE NUT TO 1ST STUD
POSITION 2ND NUT IN FINGERS	13	13	POSITION 2ND NUT IN FINGERS
ASSEMBLE NUT TO 2ND STUD	14	14	ASSEMBLE NUT TO 2ND STUD
HAND TO FINISHED ASSEMBLY	15	15	HAND TO FINISHED ASSEMBLY
PICK UP FINISHED ASSEMBLY	16	16	PICK UP FINISHED ASSEMBLY
FINISHED ASSEMBLY TO TOTE BOX	17	17	FINISHED ASSEMBLY TO TOTE BOX
DROP FINISHED ASSEMBLY IN TOTE BOX	18	18	DROP FINISHED ASSEMBLY IN TOTE BOX

REPEAT CYCLE

FIG. 26. Operator Right- and Left-Hand Process Chart—Mounting Studs —Improved Method

which, in Fig. 26, reads "pick up two nuts." It is also helpful to include a summary of the motions at the bottom of the chart.

Use of the Chart in Making Improvements.—The act of making the chart helps the observer to acquire an intimate knowledge of the details of the job, and the chart serves as the means whereby he may study each element in the operation by itself and its relation to the other elements. From such a study are generated the ideas for improvements. These ideas should be written down in chart form as soon as they are conceived. A normal study may lead to several of these ideas embracing different ways of improving the job. All of these proposals should be charted and then compared. The solution to the problem is usually found in that method which contains the fewest motions.

The degree of refinement to which motions should be subdivided in making these charts is a question of judgment. It is obvious that some breakdown of the job is necessary in order to effect any improvement, and that it is also possible to go to an extreme of refinement in subdivision of the job beyond that which is necessary for its economic solution. Figs. 25 and 26 (drawn by A. Williams) are examples of the most commonly used form of this chart. The breakdown is in sufficient detail to permit analysis for satisfactory improvement.

Importance of Positioning.—Such a chart will apply for a great variety of assembly and machine operations where fits are not too close and positioning is not a factor. However, where small parts are being assembled with close fits, **positioning before assembly** may be the longest element in the whole cycle. In such cases it is most important to give emphasis to this element by separating it from the "do" or actual assembly. Frequently the major savings are made through the reduction of such positionings by mechanizing them. This same fact also applies to the use of tools such as the positioning of a screwdriver with the slot in the screwhead. This positioning is minimized by using the self-centering screwdriver bit. Positioning an article in the hand while transporting it frequently occurs and is shown by a small circle within the larger circle. It is well to recognize this condition where present, because it has a delaying influence on the transport. It might indicate that the article should be pre-positioned in its tray or holder so that it may be grasped in the position in which it is to be used.

Figs. 27 and 28 (prepared at New York University) illustrate the **value of showing the positioning element.** In the old method, called "present method," it was necessary to position each washer and the bushing with the screw before they could be put on the screw. A study of this positioning showed that it took considerable time. In the proposed method all the positionings were eliminated with the exception of the one for positioning the screw with the steel washer, Operation No. 16 on Fig. 28. This combined positioning was made possible by providing a beveled entrance to the hole in the base of the jaws of the fixture so that the rubber bushing could be inserted without jockeying for position, and putting a semicircular stop at the rear of the holes to make positioning of the washers with the holes practically automatic. The hoppers for the washers were designed to deliver them flat on the surface of the table, so that they could be slid by finger touch until they hit the stop, whence they dropped into the fixture under pressure of the fingers.

FIG. 27. Right- and Left-Hand Chart—Assembling Screws and Washers—Original Method

Fig. 28. Right- and Left-Hand Chart—Assembling Screws and Washers—Improved Method

WORK SIMPLIFICATION REPORT

CHART #17
GROUP NO. 29

THE GLENN L. MARTIN COMPANY
BALTIMORE, MARYLAND

DATE *6/10/—*

OPERATION: *Driving Rivets on Fuselage Skin*

PURPOSE OF OPERATION: *Complete Assembly of Skin to Frame*

IMPROVEMENT SUMMARY: *Eliminated Signaling, Holds & Waits by Driving from Inside*

MODEL NO. *187* SUBMITTED BY: ______ DEPT. ______
DEPT. NO. *Body*

RIGHT AND LEFT HAND CHART OF RIVET TEAM

OLD METHOD

OUTSIDE MAN (Driving)				INSIDE MAN (Bucking)			
LEFT HAND		RIGHT HAND		LEFT HAND		RIGHT HAND	
ELEMENTS	THERBLIGS	THERBLIGS	ELEMENTS	ELEMENTS	THERBLIGS	THERBLIGS	ELEMENTS
Get one rivet from pocket	∩		*Hold Gun*	*Wait*			*Hold Bar*
Place in Hole	9 #						
Place Gun on Rivet	∩ 9	9		*Place Bar & Give Signal*	∩ 9 U	9 U	
Drive Rivet	U	U		*Back Rivet*	U	U	
Wait			*Hold Gun*	*Wait*		() U	*Give OK Signal*
TOTAL	*12*	*6*			*9*	*7*	

NEW METHOD

OUTSIDE MAN (Bucking)				INSIDE MAN (Driving)	
Position Next Rivet	9	U	*Buck 1st Rivet*	*Drive 1st Rivet* U	U
Place in Hole	#				
Move Hand to Next Hole		9	*Place Bar on Next Rivet*	*Place Gun on Next Rivet* 9	9
TOTAL	*3*	*3*		*3*	*3*

SUMMARY

	OLD L.H.	OLD R.H.	NEW L.H.	NEW R.H.	SAVING L.H.	SAVING R.H.
Operations	*11*	*5*	*4*	*4*	*7*	*1*
Holds	*0*	*3*	*0*	*0*	*0*	*3*
Moves	*6*	*3*	*2*	*2*	*4*	*1*
Wait	*3*	*0*	*0*	*0*	*3*	*0*
Signal	*1*	*2*	*0*	*0*	*1*	*2*
Total	*21*	*13*	*6*	*6*	*15*	*7*

FIG. 29. Use of Elements and Therbligs for Motion Breakdown

RCA MFG CO INC HARRISON N J — LEFT & RIGHT HAND PROCESS CHART, Page No. 1 of 1

SUBJECT CHARTED Screw & Washers for Mounting Chassis — METHOD Proposed

DATE STARTED

OPERATION Assembling — CHARTED BY D.B.P.

FACTORY NO — DEPT Final Assembly — WHY? WHAT? WHEN? WHERE? WHO? HOW?

OPERATION (Violet) TRANSPORTATION (Green) POSITION (Blue) HOLD (Orange)

1 GRAVITY FEED & DROP DELIVERY
2 PUT BOTH HANDS TO WORK
3 JIGS & FIXTURES FOR HOLDING
4 MAKE IT EASIER & SAFER

SKETCH OF WORKPLACE AND MOTION PATHS

Dist.	LEFT HAND	Draw Line or Number	Color	Draw Line or Number	RIGHT HAND	Dist.
		O T P H		O T P H		
3 5"	To C_2				To C_2	3.5"
	Pick up Rubber Bushing				Pick up Rubber Bushing	
3 5"	To Fixture F_L				To Fixture F_R	3.5"
	Insert in Fixture				Insert in Fixture	
2"	To C_1				To C_1	2"
	Grasp Rubber Washer				Grasp Rubber Washer	
2"	Slide to F_L				Slide to F_R	2"
	Insert in Fixture				Insert in Fixture	
2"	To L_1	O T P H		O T P H	To R_1	2"
	Grasp Steel Washer				Grasp Steel Washer	
2"	Slide to F_L				Slide to F_R	2"
	Insert in Fixture				Insert in Fixture	
3 5"	To L_2				To R_2	3.5"
	Pick up Screw				Pick up Screw	
3.5"	To F_L				To F_R	3.5"
	Position with Washer				Position with Washer	
	Push through Washers & Bushing				Push through Washers & Bushing	
	Release				Release	

FIG. 30a. Operator Right- and Left-Hand Chart Using Letter Columns

RCA MFG CO. INC., HARRISON, N.J.

SUMMARY

Dist.	LEFT HAND	Total	Draw Line or Number	Draw Line or Number	Total	RIGHT HAND	Dist.
	Operations	9	O	O	9	Operations	
	Transportations	8	T	T	8	Transportations	
	Position	1	P	P	1	Position	
	Hold		H	H		Hold	
	GRAND TOTAL	18			18	GRAND TOTAL	
	% of Non-Productive Work					% of Non-Productive Work	
	Distance traveled	22"			22"	Distance traveled	

If Chart is on Improved Method – Fill in the following.

LEFT HAND	Old	New	% Saved	% Saved	New	Old	RIGHT HAND
Operations	2	9			9	7	Operations
Transportations	2	8			8	7	Transportations
Position		1			1	3	Position
Hold	1	0					Hold
TOTAL	5	18			18	17	TOTAL
% of Non-Productive Work							% of Non-Productive Work
Distance traveled		22			22		Distance traveled

Additional information on saving or remarks

FIG. 30b. Operator Right- and Left-Hand Chart Using Letter Columns *(cont'd)*

CHART CONSTRUCTED BY BREAKDOWN INTO ELEMENTS.—A radically different form of right- and left-hand operator's chart has been developed by the Glenn L. Martin Co. and has proved successful in their work simplification training program. The conventional process chart symbols are not used. Instead, the job is first broken down into main divisions called "elements," such as "Get," "Place," "Do" or "Use," and "Hold," and then within each one of these elements the therblig breakdown is shown, using therblig symbols for that purpose. Fig. 29 illustrates the composition of this chart and incidentally shows a remarkable improvement in a very important operation suggested by a member of the training group. It is claimed that the inclusion of the therblig symbols does not complicate the chart for the trainee but rather helps to make him motion-conscious.

CHART MADE WITHOUT USE OF SYMBOLS.—Another form of right- and left-hand operator chart without symbols is shown in Figs. 30a and 30b. It is similar in design to the flow process chart

shown in Fig. 6a. All events are classified into four major subdivisions: Operation, Transportation, Position, and Hold. Columns are provided for each of these for each hand. Points are placed in the appropriate columns to indicate the action described on each line of the legend for right and left hand. Connecting these points helps the eye to locate each successive point, and in addition makes a pattern for the chart which has a significance. If the patterns of the two hands are different, they indicate a lack of simultaneity between the hands, whereas if the lines are parallel, as in Fig. 30a, the hands are probably making simultaneous motions, which is in accordance with good practice. The color bars lend additional emphasis to the classification of motions and to the balance of work between the hands. The form shown is that used by the R.C.A. Manufacturing Co., but the subject charted is the same as that shown in Fig. 28. A comparison may be made between these two graphic forms for effectiveness of presentation.

Micromotion Study

DEFINITIONS.—Micromotion study is the term applied to a subdivision of an operation into its basic elements or therbligs and their quantitative time measurement. This study is carried out by recording the operation on a photographic film and employing a means for timing each therblig. The method most often used is the **motion picture film** with either a microchronometer in the field, or the film run at a constant speed, and the time interval for each therblig determined by counting the number of frames on the film that have elapsed between the beginning and end of the therblig.

Another method used in research studies into motion paths is the **chronocyclegraph.** Still pictures, often stereoscopic, with long exposures, are taken during the performance of a complete work cycle and the motion paths are traced by tiny electric lamps fastened to the hands or fingers. Time is obtained by interrupting the light circuits with a controlled frequency which produces flashes or dots on the film, which may be counted. Another device which does not record the operation, but which can be used to measure very short time intervals, is the **kymograph.** This instrument employs a tape moving at a constant speed and a pen which is photoelectrically actuated by the hands when they intercept light beams, or by other means for making and breaking electric circuits. The instrument was developed and used by Professor Barnes in his studies referred to previously under "Therblig Data." (For more details on instruments see later paragraphs on Research Equipment.)

PURPOSES OF MICROMOTION STUDY.—The purposes of micromotion study are twofold. First, it is a means for **improving methods.** By projecting the pictures on a screen the motions may be analyzed and timed to any degree of accuracy desired. In certain operations employing rapid movements of hands and fingers, this medium is the only way by which these motions can be captured for analysis and study. From the film it is possible to record the therbligs and their times and then to transfer the data to a simultaneous motion-cycle

chart which presents a graphic picture of the work cycle that aids the analyst in his study of the present method and synthesis of a new method.

When several operators are performing the same operation a micromotion study of each will usually reveal differences in method. It is possible to combine the best elements of the several methods and produce an entirely new and superior method which may be taught to all of the operators.

Micromotion study is not necessary, however, in the large majority of industrial operations. It is not necessary to take motion pictures of all operations in order to improve them. One who is trained in motion study can visualize the operation in sufficient detail and apply the principles of motion economy in determining the best method to use.

Training in Understanding Motion Study.—This facility leads to the second and far more important purpose of micromotion study, to train one to understand motion study. It is only by working with film, and recording each detail of motion and its time for both right and left hand, that the student becomes familiar with the composition of work, learns to know what constitute good and bad motions, and discovers where the opportunities for correction and improvement lie. In short, it is the means whereby the student or analyst becomes "motion-conscious" or "motion-minded" and which equips him with the insight to carry on the visual analysis referred to above.

ANALYZING THE FILM.—Film analysis is the term given to making a micromotion study from a motion picture film. The film is run slowly through a motion-picture projector and observed until the analyst is thoroughly familiar with what the operator is doing. Then one cycle is selected, usually the best one, and a therblig analysis is carried out for each hand. It is better to concentrate on one hand at a time. The beginning of a cycle is usually taken after the "release" of a finished piece of work and before the "transport empty" to grasp the first article in the new cycle. Sometimes it is more convenient to begin the cycle where both hands either begin or complete their therbligs together.

ENTERING DATA ON MICROMOTION TRANSFER SHEET.—A form called a micromotion transfer sheet (Fig. 31) is used for recording the clock or counter readings and for describing the therbligs. An extra column is provided at the right-hand side which may be used for recording machine times or the operation of a foot pedal. The film is run to that point in the cycle which has been selected as the starting point and stopped on that frame which is the last frame before the action to be measured is observed to start. The clock in the picture is read and the reading entered on the first line in the column headed "Clock Reading, No. Frames." For the right hand in Fig. 31 this number is 4669.

The film is then advanced until the hand is first seen to touch a steel washer, when it is stopped and the clock is read again. The reading is now 4686, which is entered on the second line. This marks the end of the first therblig "transport empty," the symbol for which is entered in the column headed "Therblig Symbol" and on the same line.

MICRO-MOTION TRANSFER SHEET

Film No. U-2
Date Filmed May 5, 19—
By Conner

Operation Screw & Washer Assembly
Operator Lefgren
Department Radio Cabinet Assembly

Sheet No. 1 of 1
Date Made May 12
By C. & L.

Clock Reading No. Frames	Subtracted Time	Therblig Symbol	DESCRIPTION LEFT HAND	Clock Reading No. Frames	Subtracted Time	Therblig Symbol	DESCRIPTION RIGHT HAND
4661			Start	4669			Start
77	16	‿	To L_1	86	17	‿	To R_1
82	5	∩	Screw T, 1, 2	94	8	∩	Steel Washer, T, 1, 2
94	12	◡	To Center	4703	9	◡	To left hand above center
4703	9	⌂	For right hand	32	29	9	With screw
36	33	Ω	T, 1, 2	45	13	U	On screw to head
37	1	⌒	1	46	1	⌒	
42	5	∩	1, Washer	56	10	‿	To R_2
45	3	Ω	1 "	62	6	∩	Rubber Washer T, 1, 2
75	30	⌂	For right hand T, 1, 2	75	13	◡	To left hand above center
98	23	Ω	T, 1, 2	89	14	9	With screw
99	1	⌒	1	4810	21	U	On screw to Steel Washer
4804	5	∩	1, Rubber Washer	11	1	⌒	
05	1	⌒	2	22	11	‿	To L_2
10	5	∩	2, Rubber Washer	28	6	∩	Rubber bushing T, 1, 2
40	30	⌂	For right hand T, 1, 2	40	12	◡	To left hand above center
63	23	Ω	T, 1, 2	49	9	9	-With screw
64	1	⌒		63	14	U	On screw
				71	8	◡	To R_3
				72	1	⌒	

Clock Reading No. Frames	Subtracted Time	NOTES
		Time - Wink

FIG. 31. Micromotion Transfer Sheet

The description of this transport, "to R_1," is entered in the next column. The difference between these two readings is 17, which is entered in the column headed "Subtracted Time" and on the same line with the therblig symbol and its description. These subtractions are usually not computed until all the readings have been taken for the complete cycle. The value 17 means that it took 17 of the time units to perform the "transport empty." The time unit is called a "wink," which is 1/2,000th of a minute.

Other time units may be used, especially when no clock is used in the picture. In such cases it is customary to take the pictures at 1,000 frames per minute. This means that the time interval between frames is .001 min. and it is necessary merely to count the number of frames between the beginning and ending of a therblig to determine its duration directly in thousandths of a minute. To get this count a frame counter is attached to the projector and this counter is read in exactly the same way as the clock is read.

The next therblig is "grasp" and the film is run until it reaches the last frame before the hand is seen to start its movement away from the pile of washers. The clock reading, "4694," and the therblig symbol for grasp are entered in their respective columns and the object grasped, "steel washer," is entered in the description column. It was observed that this grasp was performed by using the thumb and first and second fingers. This information is recorded immediately after the legend "steel washer" by entering the abbreviations for these fingers, which are "T" for thumb and "1" and "2" for the first and second fingers respectively. In the same manner all the therbligs for the right hand are recorded. The film is then run backward to the beginning of the cycle and the same procedure followed for the left hand.

The recording for the left hand needs some further explanation. After the thumb, first and second fingers have picked up the screw and carried it to the center, where it arrives at 4694, the left hand is delayed for 9 winks while waiting for the right hand to bring up the steel washer. At 4703 "hold" begins while the right hand is engaged in positioning the washer with, and slipping it onto, the screw. During this action the first finger of the left hand releases its hold on the screw at 4736 to 4737 and grasps the washer which has been pushed down to meet the fingers of the left hand. This grasp is completed at 4742 and the "hold" for this finger continues until 4745, as does the "hold" for the thumb and second finger which for them started at 4703. At 4745 the right hand finishes putting on the washer and so the need for holding by the left hand stops.

While the right hand is getting the rubber washer the left hand is idle and this condition is called "unavoidable delay." Although the hand still retains the screw, this is not considered to be "hold" because a hold at this point is not necessary. The left hand could be employed by picking up a rubber bushing at this time which it could retain until after the right hand had put on the rubber washer, when it could pick the rubber bushing out of the left hand and put it on, thereby saving a transport to and from the bushing tray. "Hold" is resumed by the left hand at 4775 when the right hand starts to position and put on the rubber washer. The same details as occurred for the steel washer are shown for releasing the screw and grasping the rubber washer by the first and second fingers of the left hand.

SIMO-GRAPH

	ELEMENT SUMMARY	L	S	R	%
A	PLACE WRAPPER IN WORK AREA	32	12	32	12
B	LIFT 5 BOOKS TO WRAPPER	51	19	51	19
C	WRAP SIDES AND ENDS	60	23	60	23
D	TIE TWO WAYS, 1 FINAL KNOT	83	31	83	31
E	SLIDE PACKAGE ASIDE	41	15	41	15
F					
G					
H					
I					
J					
	TOTAL OF SELECTED TIMES:	267	100	267	100

(Time in .001)

Film No: EXAMPLE #1
Job Name: EXAMPLE OF FORM
Operator. A. NYMAN
Analyzed by: MARTIN WIBERG
Date: AUGUST 2, 19—
Sheet No. 1 of 1

Remarks: MAJOR ELEMENTS ARE WRAPPING & TYING: 54% OF TOTAL TIME

THIS FACT SUGGESTS NEED FOR:
1) WRAPPING FIXTURE FOR GUIDE
2) TYING MACHINE

	LEFT HAND	Symbol	Symbol	RIGHT HAND
A 32	TO WRAPPING PAPER	TE 5	TE 5	TO WRAPPING PAPER
	ASSIST R.H. IN GRASPING PAPER	G 9	G 9	GRASP WRAPPING PAPER (PAPERS STICKING TOGETHER)
	TO WORK AREA	TL 8	TL 8	CARRY PAPER TO WORK AREA
	HOLD DURING POSITIONING	H 10	P 10	POSITION PAPER IN AREA
B 51	TO PILE OF 5 BOOKS	TE 15	TE 15	TO PILE OF 5 BOOKS
	GRASP PILE OF 5 BOOKS	G 7	G 7	GRASP PILE OF 5 BOOKS

FIG. 32. Typical Simo Graph Chart
(M. Wiberg, S.A.M. Jour.)

Fig. 33. Simultaneous-Motion Cycle Chart Plotted from Data on the Transfer Sheet, Fig. 31

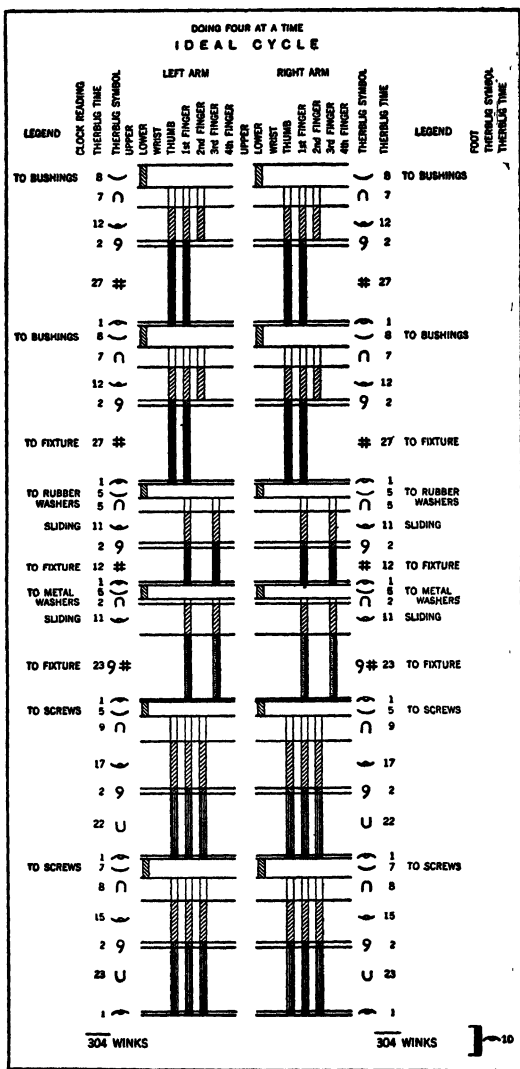



FIG. 34. Improved Method for the Operations on Transfer Sheet (Fig. 31) by Use of a Holding Fixture for Four Assemblies

SIMO GRAPH.—Simo graph is the name given to a form used for recording therblig times without recording the clock readings, and for bringing together for each therblig all the times in which it was performed from all of the cycles filmed. It presents a graphical frequency distribution of the times for each therblig which aids in the selection of representative therblig times and in the study of variations. Fig. 32 is an example of this chart. This graph occupies an intermediate position between the micromotion transfer sheet and the simo chart in presenting therblig data.

MAKING THE SIMO CHART.—**Simo chart** is an abbreviation for simultaneous motion-cycle chart and is the micromotion type of the operator process chart. Fig. 33 is the condensed form of a simo chart for the film analysis of the screw and washer assembly shown on Fig. 31. The vertical bars on each side of the time scale should be filled in with the colors corresponding to the therbligs (see color chart Fig. 14). It is usual practice to consider the whole hand as grasping, positioning, etc., but fingers used for this purpose may be recorded in the legend as described under the discussion of Fig. 31. When fingers are doing different things at the same time, the bar is subdivided vertically into as many sections as fingers used, and each section is colored accordingly. This procedure is illustrated in the chart by the left hand. At 4775 the thumb, first and second fingers started to "hold," at 4798 the first finger released and grasped again, then at 4804 the second finger released and grasped again. During this time the thumb continued its hold. This fact is made clear on the chart by assigning the left third of the bar to the thumb, the center to the first finger and the right third to the second finger. The numbers appearing in the legend identify these digits.

The same searching questions are applied to each therblig on this chart as are used with the operator's right- and left-hand process chart (Figs. 25 and 27). The redistribution and equalization of therbligs between the two hands, and the elimination of all holding and delays, are made possible by using a holding fixture. Also a change in sequence of the therbligs, made possible by the fixture, eliminates some of the positionings. The improved method which permits using simultaneous motions and employs a fixture for holding four assemblies is shown in Fig. 34. This chart is drawn on the more extensive form which is used when finger details and arm movements are shown. With a knowledge of therblig times derived from studying many cycles of work, it is possible to synthesize an "ideal" or "possibility" chart, which represents an estimate of the time in which this reconstructed cycle could be done if the best observed therblig times are used.

INTERMEDIATE FORM OF SIMO CHART.—A form of simo chart which occupies an intermediate position between the "condensed" and "extensive" types shown above is given in Fig. 35. The vertical bars representing the therbligs for each hand are divided into five columns, one for each of the five "classes of motion." Each therblig is charted in the appropriate column to signify whether it was performed with: (1) fingers, (2) fingers and wrists, (3) fingers, wrists and forearms, (4) fingers, wrists, forearm and upperarm, or (5) fingers, wrists, forearm, upperarm, and trunk movements.

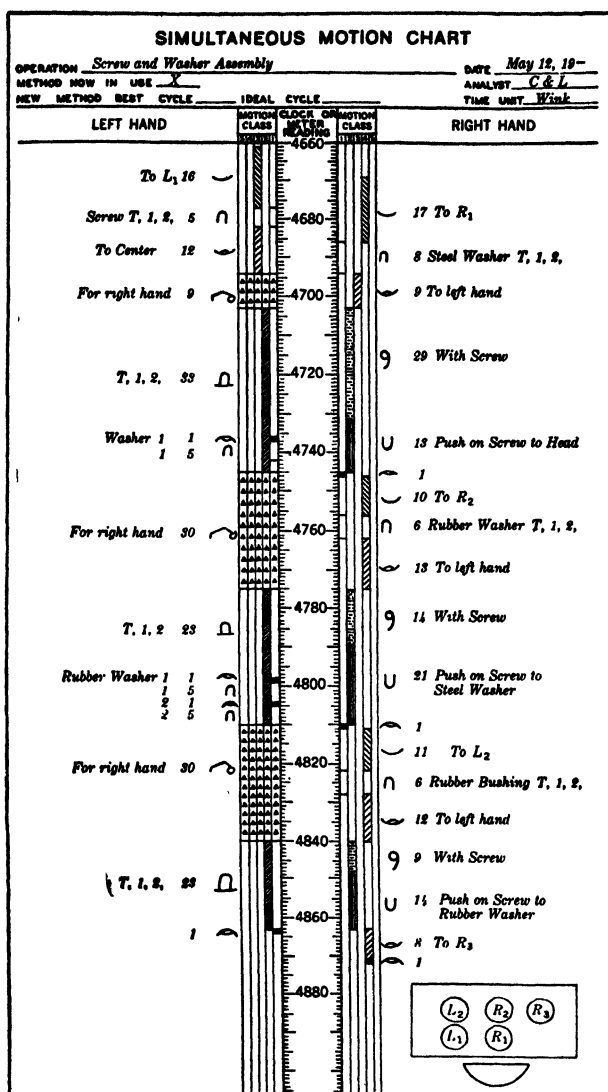



FIG. 35. Illustration of Intermediate Type Simo Chart

Motion-Time Analysis

FUNDAMENTAL PRINCIPLE.—Segur uses a modified technique of micromotion which he calls "motion-time analysis." He claims that:

> Amount of work accomplished per individual per unit time varies directly as the average effectiveness of the working habits of the organization to which the individual belongs.

This fundamental recognizes that every organization has some methods which are good and other methods which are poor, resulting in an average effectiveness when the organization is taken as a whole. These methods can be graded irrespective of individuals, that is, an operation may be performed by 90%, 80%, or say 50% method, outside of any question of personal efficiency. In the case of the 50% method, the operator performing it would be accomplishing only half of what he might accomplish with whatever amount of energy he was expending. Thus, the amount of energy that workers can put into jobs becomes, in any particular organization, on an average, nearly a constant, and the amount of work that they can turn out is likely to be proportional to the value of the method used.

DATA ACCUMULATED FOR SYNTHESES.—Over a period of 20 years Segur has accumulated data as to times required for motions of experts when putting forth their best efforts. An expert is defined as:

> A person in good health whose physical, sensory, and mental characteristics adapt themselves to any method involved, and is able to perform that method automatically, at a pace which can be maintained at operating efficiency.

These times are synthesized by means of formulas which take into account the conditions and methods involved. Here times are calculated to the fifth decimal of a minute.

Segur does not claim that any worker will maintain these ideal times continually. On a short cycle he is likely to attain such times once out of three or four performances. A percentage allowance is therefore made for fatigue, fumbles and errors, and other minor delays. This percentage varies with the number of body members, senses, and mental actions which may be operating simultaneously in performing an operation. The percentage is lowest on such operations as foundry work, where heavy loads are handled and the amount of attention is at a minimum, and highest on such operations as intricate assembly of machine parts, especially where sensory and mental attention is required by the operator. An analysis is made of any job under consideration to determine what motions are used and how they are combined. Times are then calculated as selected from the formulas and their sums checked with a stop-watch to make sure that actual work habits have been fully recorded.

These actual motions are then compared with ideal motions and improvements made according to the rules of the correct human motion. As permitted by operation and production limitations, one or more synthetic improved methods are set up. The times for these synthetic

methods are calculated from predetermined formulas and entered on the analysis. The best practical method is selected and used as a basis for instruction of operators. The selected method is in sufficient detail to permit accurate and specific instruction to operators and the allowances are added to the time so that the job is rated before any actual instruction begins.

The data secured on the original analyses form the basis for further improvement work or rate-setting on other similar allied operations. Since the time values and the analysis are based primarily on conditions

Abbreviation	Therblig	Definition
T.E.	Transport Empty	Act of moving a Transportation Means to a point to get a load; or to a position to act against a resistance.
T.L.	Transport Loaded	Act of moving a Transportation Means with a load or against a resistance.
P.P.	Pre-position	Act of preparing the Transportation Means, or the object being transported, for the next operation to be performed.
G.	Grasp	Act of securing control of an article.
R.L.	Release Load	Act of relinquishing control of article.
H.	Hold	Act of maintaining effective control of an article for a definite period of time.
P.	Position	Act of assuring safe and accurate place control of an article or tool.
U.D.	Unavoidable Delay	Delay in an operation beyond control of operator.
A.D.	Avoidable Delay	Delay in an operation under control of operator.
B.D.	Balance Delay	Delay caused by a difference in time between opposite similar member movements in an operation.
D.	Direct	Act of examining locations and article (for size, form, shape, position, etc) to determine the method of action to be used by working members.
I.	Inspect	Act of examining anything for quality, quantity, area, and other characteristics, to determine its degree of likeness to a standard value.
SE.	Select	Act of choosing one or more articles from a group of different articles in a known location.
S.	Search	The act of finding or attempting to find the location of one or more articles.
PL.	Plan	The act of devising a course or scheme of action.
R.	Rest	The delay caused by fatigue necessary for working members and sense organs of the body to regain the required strength or condition to perform an operation.
U.	Use	The occurrence of mechanical and chemical reactions in conjunction with muscular and sensory movements.

FIG. 36. Definitions of Therbligs

rather than on performance, a much closer check can be kept on methods and operating conditions than is possible on time study of operation performance alone. The usual pains are taken in teaching new methods and breaking down old work habits and building new ones until automaticity is achieved.

COMPARISON WITH GILBRETH TECHNIQUE.—Segur uses 17 therbligs commonly in operation analysis study (Fig. 36). These differ from the Gilbreth therbligs as follows:

1. Therblig "find" is omitted, included with "search."
2. New therbligs "direct" and "balance delay" are added, the latter upsetting the original scope of unavoidable delay.
3. Therbligs "transport loaded" and "position" are given broader definitions to include the therbligs "assemble" and "disassemble," that is, position ends after assembly and transport loaded begins before disassembly.

RESULTS FROM MOTION-TIME METHOD.—Segur points out that working habits constitute the main cause of deviation from the best performance and the best time which is theoretically constant for all individuals. He says: "We try to control speed of all individuals in the plant to about 10% to 15%. This means, of course, that we do not get the working habits identical, but nearly so." As in all micromotion, the emphasis is placed on correct habits rather than on speed as such. It is claimed that rate revisions are very rare and that the average increase in output per man-hour over a wide range of operations has been 70%. Furthermore, it is thought that the benefit arising from the viewpoint of "motion-mindedness" established is greater than the benefit above mentioned, in that close observation and analysis tend to become habitual on the part of all plant personnel.

Selection of Motion-Picture Equipment

COMMENTS.—Motion pictures are used as an analytical tool in making micromotion studies and as a means for illustrating the application of the principles of motion economy in the teaching of motion study or work simplification. It is possible to give only comments on the selection of equipment for such purposes, because each company decides for itself how far to go with the work and hence how much equipment to buy. Later paragraphs discuss the question of Research Equipment.

MOTION-PICTURE FILM.—The first decision to be made is whether to use either 8-mm. or 16-mm. film. If the film is to be used for teaching, the 16-mm. size is recommended because large-size pictures are projected from it with greater clarity and definition of detail than from the 8-mm. film. Also, the use of sound film is restricted to 16 mm. and the available films in this field, both sound and silent, which may be secured from rental libraries are in the 16-mm. size. If the film is to be used solely for making micromotion studies where projection is usually on a small screen and is viewed by one or a very few analysts at a time, the 8-mm. film may give satisfactory results. However, the best projection equipment which has been designed especially for micromotion analysis is in the 16-mm. size.

In selecting a film for taking pictures, a fine-grain, medium-fast film in black and white is recommended to secure sharp pictures for a wide latitude of lighting conditions. Where it is not desirable to employ auxiliary flood-lighting, the very fastest or most sensitive black and white films should be used. Color pictures have a strong appeal but cost approximately twice as much as black and white. Color film comes in two types, one for natural daylight and the other for artificial light. It is relatively low in sensitivity as compared with the medium and fast black and white films and requires auxiliary flood-lighting of uniform distribution without shadows. Since it does not have the latitude of black and white film, details in shadow are lost.

To determine the proper level of illumination for the type of film being used, or the proper film to select for a given level of illumination, the use of an exposure meter of the photoelectric type is recommended.

CAMERA.—In selecting a camera, special consideration should be given to capacity, drive, lenses, and view finder. The camera should take a 100-ft. roll of film, and should be capable of being operated for the entire 100 ft. without stopping. Since no spring-driven camera will run continuously for 100 ft., a crank permitting hand operation is essential. An electric motor drive is obtainable with some makes but is expensive. The spring drives in cameras will run between 20 and 40 ft. of film at one winding. The longer the run the greater is the opportunity to use the spring drive which produces steadier pictures than those taken with a hand crank.

The lens is the most important factor in determining quality of picture. The camera should be capable of taking interchangeable lenses with focusing mounts. There should be a wide-angle lens of 15-mm. focal length for taking pictures in cramped quarters, and a 1-in. lens for normal conditions. A 2-in. lens is convenient for getting close-up views. If the camera is to be used without auxiliary flood-lighting, these lenses should be "fast," that is, with maximum diaphram openings of f/1.9 or f/1.5. On the other hand, if adequate auxiliary illumination can be provided, less expensive slower lenses with smaller openings, f/3.5, can be used. Also, when pictures are taken with smaller diaphragm openings, the depth of focus is increased, which means that the range over which objects will still be in sharp focus is increased. This factor is even more important at the relatively short range at which most motion-study pictures are taken.

The view finder should show the exact field of the lens being used. This determination may be most accurately made with a reflex finder which shows on ground glass the image projected by the lens. If the camera lacks this feature and instead has only the usual eye-level finder, this finder should be adjustable for all focus distances to compensate for the parallax between the optical axis of the lens and that of the view finder.

MICROCHRONOMETER.—A microchronometer is placed in the field next to the operator to record the passage of time on the motion-picture film. Two types have been developed and are normally available. One uses the clock dial divided into 100 divisions and hands making 20 and 2 revolutions per minute (A. Williams, Haydon Mfg. Co.). One make of this type employs a third hand making .2 r.p.m. (Telechron Co.). The other type is called a wink-counter (developed by

Professor David B. Porter, of New York University) and employs revolving dials bearing numerals which give a direct reading (Veeder-Root Co.). This type is more quickly and accurately read than the clock type. Both give a reading to 1/2,000th of a minute, which is the Gilbreth "wink."

PROJECTOR.—There are two uses for a projector. One is for showing pictures at normal speed to large groups of people, and the other is for making a motion analysis of an operation from a film. For the first purpose, any of the standard makes of projector will be found satisfactory. However, since film is used for many repeated showings, it is wise to give consideration to those features on projectors which are designed to protect the film.

For analysis work a projector that permits showing brilliant still pictures without damage to film is essential and it must permit operation or movement of film, frame by frame. These features have been applied to a standard make of projector by Professor Porter through a device which is operated by one hand and controls the projector for frame-by-frame movement, both forward and reverse, and for speed of continuous movement from slightly above zero to full speed. The film may be operated at a very slow speed without excessive flicker, thus making it possible for the eye to follow the motions more deliberately without losing the continuity of action. This same projector may be operated at normal speed without noticeable flicker where not over a 500-watt lamp is used with a 60-in. projection screen and proportionately less wattage with smaller screens.

SCREEN.—For normal projection the beaded glass screen is satisfactory. However, for film analysis a very smooth, hard surface with a sprayed aluminum paint finish is better than the beaded glass, because it gives clearer definition to still pictures. Presdwood gives a satisfactory surface.

Research Equipment

KYMOGRAPH.—An instrument known as the kymograph, referred to previously under Micromotion Study, is used for measuring time to 1/1,000th of a second. It consists of a rapidly moving tape upon which lines are drawn by pens which are are electrically actuated in a direction perpendicular to the travel of the tape to produce jogs in the lines. The circuits which control the pens may be opened and closed by photoelectric or mechanical means. This instrument has been used in the research carried on to determine therblig times. Professor Ralph M. Barnes, of the University of Iowa, developed it. It is not commercially available.

MARSTOCHRON.—The Marstochron is a kymograph whose tape runs slowly at 10 in. per min. Marks are made on the tape by manually depressing keys. A scale graduated to 1/50th in. makes possible readings to 1/500th min. Intervals as short as one 1/100th min. may be recorded. This instrument is used mostly in time study but can be used for a rough analysis in man-and-machine cycles. Tape speed may be increased to 50 in. per min. by interchanging the driving motor.

CYCLEGRAPH.—In motion-picture films the exact path and length of motion are not clear enough for all kinds of measurement and training. The Gilbreths' cyclegraph overcomes this lack. Under this latter method small electric lights are attached to fingers, elbows, and head of operator, as may be desired, circuit wires being held close to the body in a way not to interfere with motions. When an ordinary still-picture time plate is exposed under this method during a brief cycle of work, the path of each motion will appear on the plate as a streak of light, making a permanent record of the path in two dimensions. The procedure causes a series of still pictures to be superposed one on another.

STEREO-CHRONOCYCLEGRAPH.—By means of a stereoscopic camera, a cyclegraph motion-path picture giving an approximation of the third dimension (depth) may be obtained in the picture. Such a record is called a **stereo-cyclegraph.** A final step in the sequence is the addition of the time element to the picture. A cyclegraph (still) picture taken with a stereoscopic camera, where the plate is exposed throughout the duration of a work cycle and the time element is recorded, is called a **stereo-chronocyclegraph.**

The time-recording element may be incorporated by putting an interrupter on the light circuit which flashes lights on and off at a uniform rate per second. The photograph will then show a line of timed dashes instead of a continuous path as in the regular stereo-cyclegraph. By counting these dashes the time of motion can be very accurately determined. By controlling the combination of current in the light circuit and thickness of filament in lamps, it is possible to cause quick lighting and slow extinguishing of light. The dashes then produced in the picture are blunt in front and tapering toward the rear. By this means direction of movement is photographed. By further improvement the timing of interruptions for different lights can be differentiated so that various motion paths can be identified.

Another method of producing flashes of light upon the film, used by Professor Barrett Rogers, is to employ a rotating disc in front of the camera lens. The disc, which is rotated at a constant speed, is provided with slots which produce the flashes from the continuously burning lamps carried by the operator. The difficulties of circuit interruption and the unsatisfactory separation of spots of light attendant thereon are thus eliminated. By using kodachrome film and colored lights, differentiation of the paths made by several lights is made easy.

MULTI-FLASH PICTURES.—Another method of measuring motion paths and their speeds is by the multi-flash technique developed by Professor Edgerton of Massachusetts Institute of Technology. The R.C.A. Manufacturing Co. has developed for its own use suitable equipment for taking these pictures for micromotion analysis.

When the pictures made under the above methods are viewed stereoscopically, the paths of motion are seen in three dimensions and time is obtained by counting the flashes. There is no complete equipment commercially available for making and showing such pictures. However, stereoscopic lenses may be obtained for certain standard cameras and projectors which make it possible to project three-dimensional pictures on a screen without special stereoscopic cameras and projectors. Special polaroid glasses are furnished for the observer to wear when these pictures are projected.

It is also possible to take and project moving pictures stereoscopically but the limitation of viewing them through special glasses has prevented their general use in training programs, where the films are to be viewed by large groups of people.

PENETRATING SCREEN.—The use of a penetrating screen in taking motion pictures, to give dimensional measurements, is an improvement over the cross-sectioned background. A sheet of black paper about 3x3 ft., with white lines upon it in squares of convenient size, usually 4 in., is set up in the plane of the photograph to be taken, at point where motions are to be enacted. If a partial exposure of the right timing is made, the cross-sectioning can be photographed on to the film before it is used for the study. The subsequent photograph will show motion paths in relation to cross-sectioning, thus allowing exact linear and speed measurement. Several photographs, each with its screening, can be taken from different directions simultaneously if desired. In such operations as folding cloth the additional views may be necessary. Telephoto lenses can be used when the camera is at a distance from the subject.

WIRE MODELS.—If desired, wire models of motion paths may be made and mounted on cross-sectioned stands for examination (Fig. 37). They may serve as scientific records and as teaching devices. To make the models complete, tapered light dashes can be imitated by painted spots on the wires. Wire models should be checked against original photographs by being themselves photographed stereoscopically.

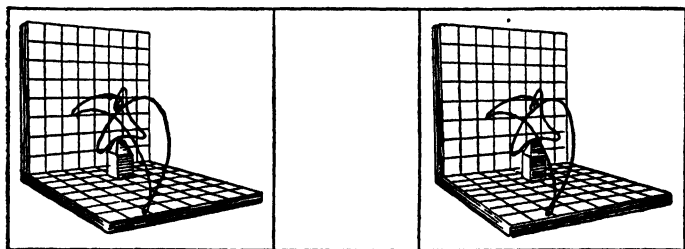



FIG. 37. Illustration of Wire Model (stereoscopic view)

If the object is to transfer skill in the shortest possible amount of time, the model can be shown to the learner at the outset. Its advantages to the learner over the motion-picture record are that it is tangible and not dependent on visualization, that it can be studied from any angle, and that it can be perfectly followed with the hands, practicing speed as well as the path. The worker thus begins to think in terms of elementary motions. For the expert the motion model is useful in studying existing motion paths and possible lines for improvement. He can experiment with and improve elements until they show indications of efficient motions, smoothness, grace, habit, decision, and freedom from fatigue.

Applying Work Simplification

LIMITATIONS WHEN HANDLED BY STAFF SPECIALISTS.—During the years of formulating the principles of motion economy and developing the technique of process and operation analysis, the application of these new tools to operations within industry was naturally carried on by specialists. The usual procedure was for these men, acting in either a consulting or staff capacity, to make the necessary studies and recommendations for improvement of operations. This method produces results in those industries where a large number of people are working on a few highly standardized operations which run continuously. However, it proves to be entirely inadequate in those industries which have a diversity of manufacturing operations on many parts and assemblies. It becomes physically impossible for a few staff men to cover more than a small percentage of the operations needing improvement. Even if the number of men were increased many times, the method of introducing changes in work methods by staff specialists has serious limitations for psychological reasons, namely, that supervisors and workers resent criticism and resist new ideas. When a staff specialist tries to impose an improved job method on the supervisor or foreman who is responsible for the operation, the latter is inclined to look unfavorably on the suggestion because he immediately reacts to defend his own method, and sees in the proposal an implied criticism of himself.

Secondly, the new ideas are resisted not so much because they are new but because their adoption entails a change in an established habit. It requires effort to unlearn the old and learn the new ways. There is also the element of fear or dislike of the thing which is not understood. When a foreman is presented with a new method which embodies principles of motion economy of which he has no knowledge, he fears it because he is at a disadvantage when it comes to training the operators. Even if someone else does the training, he is placed in an unfavorable position with respect to those under him because they soon find out that he does not know about these new methods of work.

INTRODUCING THE METHODS ON A WIDE SCALE.—The psychological hazards are avoided by teaching all those in an organization who are responsible for work methods the principles of motion economy and the techniques of work simplification. This undertaking implies a major training program which may reach everyone in the organization. It should reach those in all levels of supervision where rests the responsibility for getting work done, those in engineering design of product and of machines, and in tool design. In this way everyone is possessed of these new techniques of work analysis and there is no longer the fear of the unknown. With these tools in hand those who are supervising work evolve better job set-ups for new work than they otherwise would do, and will develop improved methods for jobs in process. Resistance to change is overcome when the change is self-imposed as a result of new knowledge and individual creative thinking.

Since the operators on the benches and machines are the ones whose habits are mostly interfered with by a change in method, and since they determine many of the details of their own jobs, it is important to include them as well as the supervisors in a training program. Although

training on the operator level has not been done to the same extent as on the supervisory level, it has been done with results that are measured in the worthwhile suggestions obtained for improving methods, and in a willingness to cooperate with supervisors when changes are imposed from above, because of a more intelligent understanding of the reasons for making the changes.

The benefits of introducing work simplification through a broad training program are found in the greater number of improvements made as compared with the staff specialist method, for the reason that many more minds are working on improving methods. It is physically possible to reach every job with some degree of study for improvement. But of equal importance is the benefit to employee morale through the stimulation of a greater interest and satisfaction in the job. The worker is the person closest to the job and has far greater knowledge of details than anyone else. When he is instructed in methods of job improvement and when his suggestions are solicited, substantial savings, which would not otherwise have been gained, are achieved.

BASIS OF THE APPROACH TO WORKERS.—When starting a training program it should not be assumed that workers will understand why it is a desirable thing for the company and for themselves. They may be suspicious of ulterior motives on the part of the management. No management should attempt to employ these techniques of work simplification for the exploitation of the workers. It is important at the very beginning of the program to present an objective to which both management and workers can subscribe and which the program is designed to further. Such an objective is to make a better product at a lower cost and at the right time. It is well to be entirely frank in discussing this objective and to make an appeal on a purely selfish basis. namely, threats to the company and the workers' jobs from lowered selling prices of competitors who have introduced improvements and cut costs. It should be emphasized that the pressure for lower costs is ever present and that the only true way to lower costs is through labor-saving methods and not by lowering wages. There must be a frank declaration of policy by management stating that there will be no lay-offs due to labor-saving methods resulting from work simplification, that such savings will be used to reduce selling prices in order to attract more business and thus maintain employment and increase wages and profits.

In addition, the worker's natural resistance to change and to new ideas should be frankly admitted so that opposition may be partly overcome, and helpful suggestions made to workers may be received without resentment.

PLANS FOR CARRYING ON THE INSTRUCTION.—The above introductory material for preparing the way usually takes up the opening one or two sessions in the program. Typical training programs contain 10 to 15 sessions, usually spread one week apart but sometimes given on consecutive days. Sessions are 1 to 2 hours in length. Subject matter is presented in about the same order in which it is treated in this Section. The content of the program is altered to suit the needs of those at the different levels at which the course is given. Methods engineers and motion and time study engineers are given the whole program, including micromotion analysis, because they are the

staff specialists who are called in to help work out the details in the suggestions submitted by the line supervisors and workers. They will need to know how to make micromotion studies from film analysis when such techniques are needed for the solution of difficult problems. Lay-out men will use the operation and flow process charts as first steps in plant layout, but will not need micromotion study training. Foremen and supervisors will use the flow process chart as it affects the routing of work within a department and the elimination or combination of operations, and the operators' right- and left-hand charts and man-and-machine charts, but will not make micromotion studies. The operators need the flow process chart, and especially the right- and left-hand charts, and the man-and-machine charts for those operating machines. All levels should get the basic principles of motion economy.

A much streamlined and condensed course of five 2-hour sessions, known as job methods training, was devised by the War Manpower Commission for teaching the maximum number of foremen in the shortest possible time the fundamentals of motion economy and job study. It fulfilled a most urgent need very successfully but was not a substitute for the more complete programs in work simplification.

Work simplification programs are designed to stimulate thinking on the part of workers and to encourage them to develop better ways of doing their jobs. Especially when rewards are offered for new ideas these programs result in a flood of suggestions which require review by the methods specialists in order to determine their acceptability. Minor improvements that do not involve expenditures can be decided on the spot by a foreman and put into effect, but the majority of suggestions require some change in a tool or a new jig or fixture that can be made only in a toolroom or special shop. It is imperative, therefore, when embarking on a work simplification training program, to set up an adequate organization for reviewing all suggestions promptly to determine costs of installation and net savings from first year's operation so that awards may be paid, and for making the necessary tools, jigs or fixtures, or changes in layout. There is nothing more damaging to the success of a newly inaugurated training program than the lack of an adequate system for the prompt handling of suggestions, the making of awards, and the installation of the new methods.

SECTION 9

INSPECTION

CONTENTS

PAGE

Instruments

Classification of Inspection Instruments

Methods of Gaging

Glass Precision Gages

Army Ordnance Gaging System

SECTION 9

INSPECTION

DEVELOPMENT OF MODERN INSPECTION.—The evaluation and growing importance of modern inspection have been significantly traced by G. S. Radford. In early factory practice inspection involved merely looking at the work. Dimensions were either scant or full. Then through a gradual development, following in step with the attainment in the mechanical arts, through more accurate measuring devices and better machinery, measurements were taken in hundredths of an inch, then thousandths, then ten-thousandths. Today inspection makes use of mechanical devices which give far greater speed, repeatability, and sensitivity than is possible through human agency. Such progress in material ways calls for adequate and similar adjustments in inspection organization. Following this trend, modern inspection has become recognized as (1) the instrument for quality measurement, (2) a powerful factor in quality control, which should be (3) an independent function.

DEFINITIONS.—A broad definition of inspection which is generally accepted is that of Dexter S. Kimball:

> "Inspection is the art of comparing materials, product, or performances with established standards."

A somewhat narrower definition is adopted by Alford:

> "Inspection is the art of employing tests, preferably by the aid of measuring appliances, to observe whether a given item of product is within the specified limits of variability."

In machine-shop practice inspection often connotes a procedure to determine if materials, parts, and assemblies conform to drawings and specifications in every respect.

Modern, large-scale manufacture of products like sewing machines, vacuum cleaners, automobile engines, etc., would be impossible were it not for the development of the tolerance system and inspection procedure which keeps performance under control. Combined, they permit employment of less skilled labor to produce a superior product. Interchangeable manufacture presupposes accurate production of each component in the place or plant of its origin so that no supplemental machining or labor is required at point of assembly.

SCOPE OF THIS SECTION.—This Section is concerned with inspection in the somewhat narrower sense of the last two definitions. Its emphasis is on inspection of product rather than process, and of the qualities of dimension and finish. This is the type of inspection which is

of widest application throughout industry, is a common denominator of the greatest range of manufacturing industries, and has its techniques most highly developed. There is, of course, corresponding inspection in the process industries, but it commonly involves setting up standards peculiar to the particular industry, often under laboratory rather than shop control, and much of it is merged into, and difficult to separate from, the processes themselves. For these reasons such inspection is not considered here.

Furthermore, the aspects of inspection emphasized here are those connected with manufacturing operations as distinguished from the checking of incoming materials and parts against purchase specifications.

THE FACTOR OF ACCURACY.—Accuracy in the absolute or scientific laboratory sense is not a factor in shop practice. The use of the term is merely to indicate a degree of approach to the actual dimension. There may be less than two pounds of steel, worth but a few cents, in a set of precision gage blocks, yet the price of the set may be several hundreds of dollars, because of the labor involved in making the blocks "accurate" within, say, two millionths of an inch of specified sizes. They are not accurate but are sufficiently so to serve all practical purposes. Therefore, no more time or money need be expended to make them "more accurate" than is necessary. Accuracy and precision are terms having only relative values and are not economically attainable in machine-shop practice.

The primary consideration here is with inspection as it applies to dimensional control, and quality of finish, or surface aspect, of components in question.

Organization of Inspection

PLACE OF INSPECTION DEPARTMENT IN PLANT ORGANIZATION.—As to the best organization for inspection department, much depends on size and layout of plant, type of product or products, and quality and standards to which work is produced. Basically, however, inspection should be an independent function unconcerned with other than getting the work through inspection, which is but a way station on the production line where bottlenecks can readily originate.

Coordination with Other Departments.—Inspection is usually placed coordinate with the manufacturing, production control, and plant engineering departments, and the chief inspector reports to the works manager or factory manager as the chief plant operating executive. In certain industries, for example aircraft manufacture, the practice is for him to report to the chief engineer or general manager. In control of quality in manufacturing, the relationship between engineering, manufacturing, and inspection departments has been compared by Radford to that existing in the national government between the legislative, executive, and judicial functions. Engineering sets the design, as the Congress passes the laws. The manufacturing superintendent puts the design into actual form, as the chief executive applies and administers the laws. The inspection department interprets engineering design and decides whether

the manufacturing department has followed the intent and requirements in making the product, as the court decides, on the one hand, whether laws are constitutional or whether, on the other hand, the executive administered them according to intent or exceeded their provisions.

The accompanying diagrams (Figs. 1-4) show the relationship between inspection and other departments and the organization set-up for inspection work in typical well-known companies. In Fig. 1a, the place

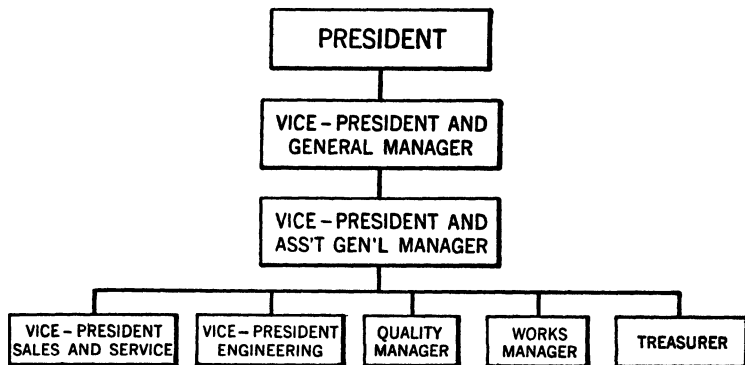
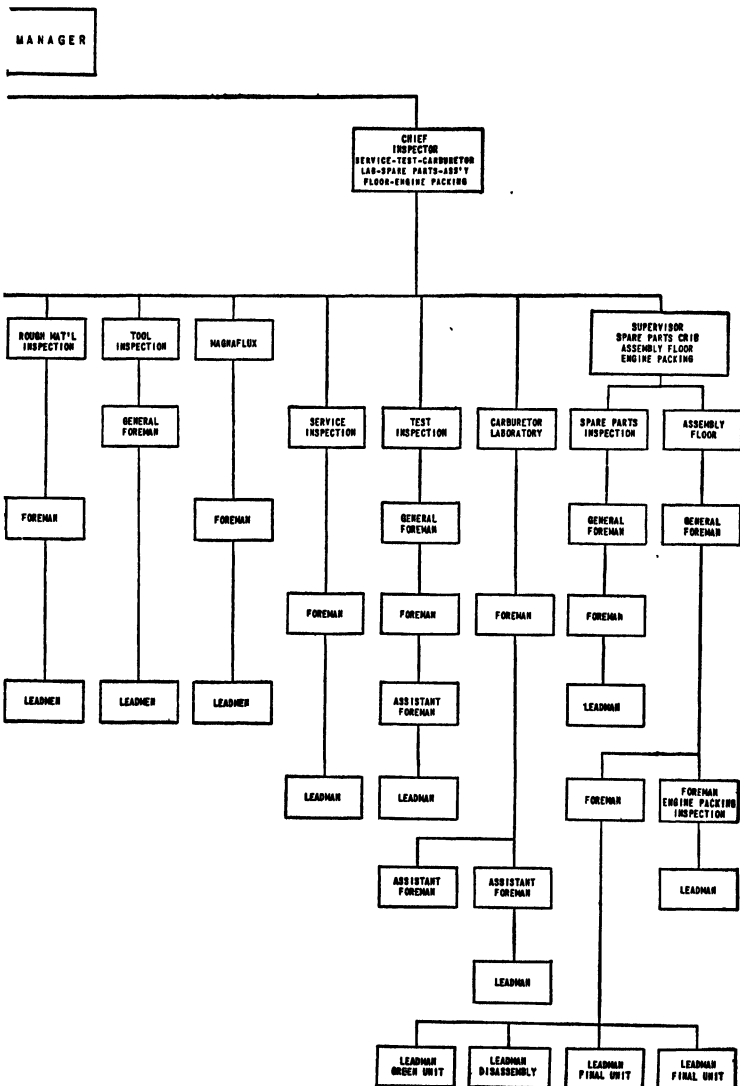



FIG. 1a. Place of Quality Control, Covering Inspection, in an Aircraft Engine Company

of inspection in the Wright Aeronautical Corporation is shown. Inspection here is associated with quality control and comes under the jurisdiction of a quality manager reporting to the assistant general manager. Fig. 1b gives the detailed breakdown of the function in this company, showing the subdivisions of inspection, the supervisors in charge of the work, and the interconnection of the various units with one another. A feature of the method of organization is the arrangement whereby manufacturing inspection is divided into two sections, one covering production and the other salvage, while a separate unit carries on inspection dealing with service, tests, carburetor laboratory, spare parts, the assembly floor, and engine packing.

The organization for inspection in The Bullard Company, manufacturers of automatics and other machine tools, is illustrated in Fig. 2. The chief inspector reports to the works manager, as do the heads of the other operating divisions. In this company, simplicity of organization is stressed. Inspection, therefore, is subdivided into only four units—receiving inspection, metallurgy, central inspection, and final inspection.

The Remington Arms Company delegates its extensive inspection activities to a manager of quality for the entire company, who reports to the production division manager. The manager of quality serves in an advisory and counseling capacity to the quality control supervisors in the plants, who report to the product engineering and control superintendent. The plant quality control supervisor has three groups under

FIG. 1b. Organization of the Inspection Department

in an Aircraft Engine Company

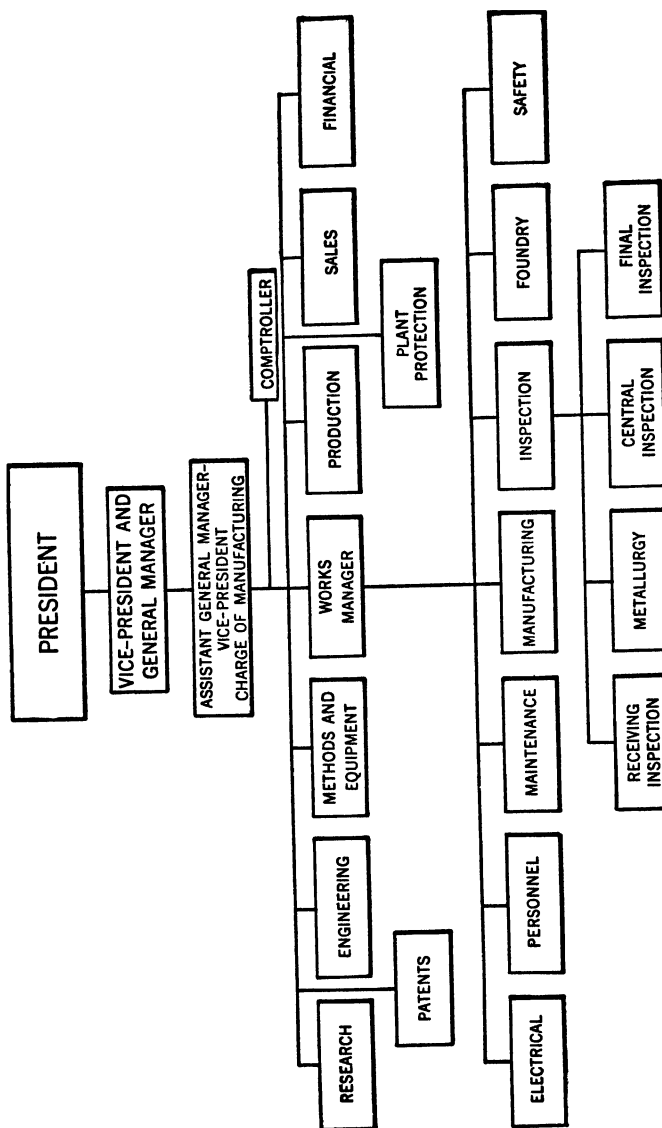



FIG. 2. Place and Organization of the Inspection Department in a Machine-Tool Company

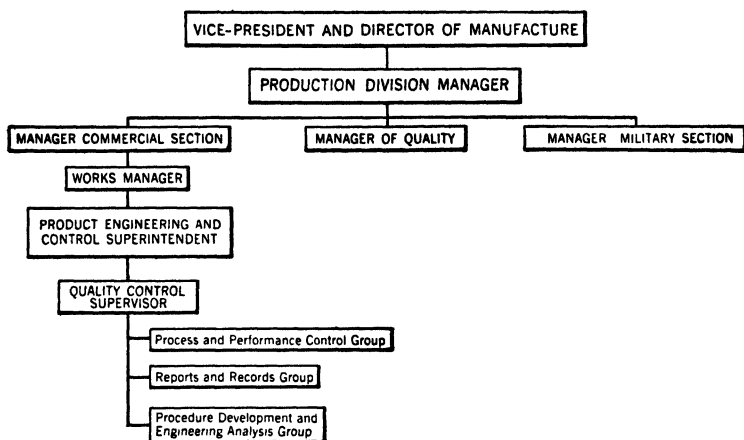



FIG. 3. Inspection Department Organization in an Arms Manufacturing Company

his direction—process and performance control, reports and records, and procedure development and engineering analysis (see Fig. 3).

Figs. 4a and 4b (E. W. Ritter) show somewhat different plans of organization where laboratory control is a feature and inspection is directly associated with processing operations.

Cost Control as a Factor in Organization.—In one particular case, where a highly developed plan of quality control was in operation, inspection was placed under the manufacturing departments. The cost of inspection in these departments was budgeted and also economic percentages of spoilage were set. The cost of inspection to throw out bad work in the producing departments was checked against the cost involved in reducing actual inspection and allowing assembly departments to detect and reject such spoilage in excess of the economic normal. When a department, under restricted inspection, passed along too much defective work, discovered by user departments, the extra cost was charged back against the producing department and thus became a cost-club compelling it to improve its work. The cost of extra inspection, however, would overrun the department's budget and become another cost-club. The only alternative was to call in the quality control department, which would find and help correct the cause of the high spoilage, and thus bring the producing department back to normal spoilage and normal inspection cost.

PERSONNEL.—The ratio of inspectors to productive employees in departments in the same plant varies with the class of work to be inspected. Some work demands 100% inspection, other work is based on liberal tolerances requiring but a small ratio of inspectors to workmen. Proportional to size of working force, there must be the required num-

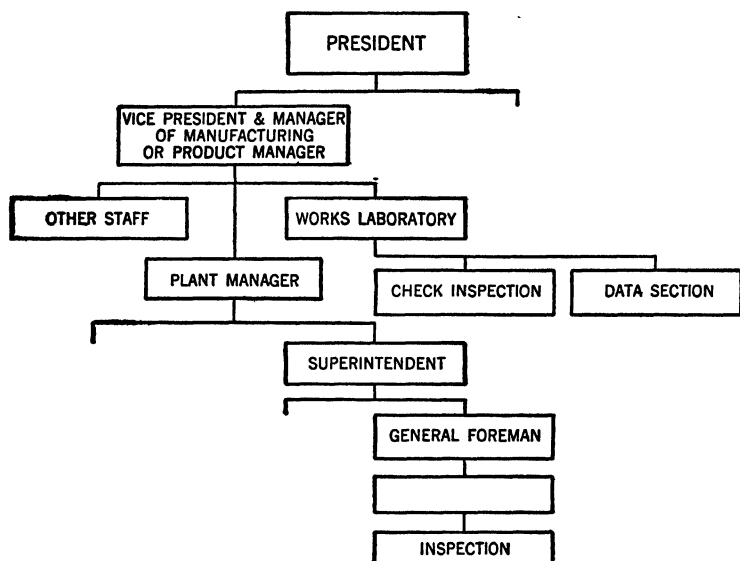
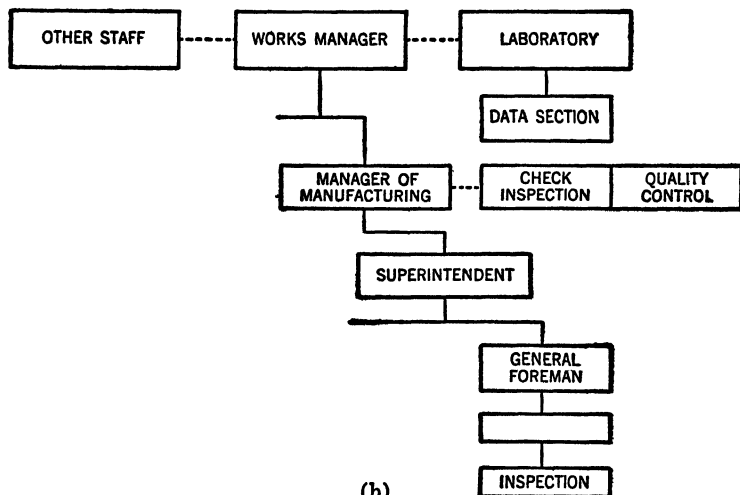



Fig. 4. Types of Inspection Organization with Laboratory Control

ber of inspectors, group leaders, subforemen, foremen, a general foreman, a group of experts for special assignments, and a chief inspector and his assistants.

The **chief inspector** must be a man of executive ability, able to select and guide a staff of men, and knowing how far to make use of experts when necessary. A wide general experience in industry rather than specialized knowledge of particular work is desirable. His sphere will include, usually:

1. Selection and training of inspection staff.
2. Organization of men into such groups and in such relation to work as may be best, i.e., planning the inspection framework.
3. General supervision of gages, tools, templates, and other precision devices, both as used in production and for testing purposes.
4. General supervision, in some cases, over salvage work, wherein defective parts are worked over into useful forms for avoidance of loss and waste.
5. In some plants the chief inspector has jurisdiction over testing laboratories, etc., in which raw material is examined and passed on. This is particularly the case where the same laboratory equipment is utilized for testing and controlling process work. In other cases, examination and analysis of raw materials is carried on by a separate organization.
6. Expense budget for his department and operating under this budget.

The **assistant chief inspector** provides an understudy, and aids the chief inspector in directing the work of the department and takes the place of the chief inspector in the latter's absence. Sometimes he has special charge of some important part of the routine, wherein close supervision is normally necessary. He is available to take charge of important special operations, changes in methods, advising on tools, gages, etc.

A **staff of experts** on particular tool and inspection problems is sometimes conveniently located in the main inspection department to handle special assignments that would interfere with routine duties of regular line organization inspectors.

In large plants a **complaints division** is also located in the main inspection office. Such a division handles complaints of defective workmanship, or defective material, as received from sales and service departments in the field. In some cases future shipments are held up until causes of complaint have been located and rectified. The division acts also as a clearing house for all reports on defective workmanship, doubtful points of design, and defective material in work in process. Information on errors and mistakes is analyzed and grouped, so that the conditions responsible are disclosed without undue delay.

A **supervisor of gages** is also an important figure in an inspection organization. Purchase or design and building of all gages and measuring instruments, and training of men in their proper use are his principal duties. The gage supervisor and his assistants should be located in the main machine-tool and gage department, so that contact is maintained with manufacturing tool supervisors and their problems.

Foremen inspectors are responsible for control of quality in a particular division of manufacturing operations. In some plants a general foreman inspector coordinates these activities, but more often the fore-

men inspectors report directly to the chief inspector. Each foreman inspector has a staff of inspectors, sorters and counters, often subdivided into groups under subforemen or group leaders. Each foreman inspector should be located in the center of the manufacturing territory for which he is responsible.

The **main office force** of the inspection department should be kept at a minimum number.

An inspector's job is to inspect, rather than to sit at a desk doing work that should be done by a clerical force. It is therefore desirable to keep inspectors on the "firing line" at all times, and to organize routine work with that end in view.

Routine work of the main office will usually include:

1. Personnel matters—pay, promotion, training, etc., of employees of the department.
2. Checking up work of inspectors to see that prescribed standards are being adhered to.
3. Maintaining contact with the production engineer to coordinate inspection and production requirements.
4. Statistical work affecting control of quality.

WOMEN AS INSPECTORS.—For many inspection jobs women have proved most satisfactory, being generally careful, patient, and better suited than men to repetitive types of inspection. Careful training is necessary, however, and in general this training should be for specific kinds of inspection rather than for all-round inspection. Some women are adept at setting-up work on a surface plate, others on comparators, others on special gaging fixtures, but all are not usually equally proficient on all kinds of inspection. Great caution must be observed against discoloration and corrosion of fine instruments or brightly finished surfaces of work due to excess acid condition in workers at certain times. At such times, or when perspiring, the hands should be rubbed with "Pro-tec," a harmless, white salve-like preparation easily washed off when through work.

QUALIFICATIONS OF INSPECTORS.—A prime requisite of an inspector is that he can be depended upon to follow instructions implicitly. On the other hand, a degree of intelligent appreciation of the purpose of tests, and their relation to the needs of manufacturing, is desirable. A certain amount of technical or factory experience is of benefit, but should be balanced by a realization that shop work is not inspection work, and that the latter is a separate technique to be acquired.

In some cases, especially those where standards are not of the yes-or-no order, and particularly where they are not measured by instruments, reliance on the inspectors' **judgment and experience** is necessary, but this is not without dangers of its own.

In a certain instance in the inspection of glass blanks for imperfections, standards of inspection performance were attained by having the individual inspectors go over work with the foreman inspector until it was felt that the dividing line between good and bad was generally understood. All would go well for a few days and then rejections would pile up, which on revised inspection were found to be unjustified. Investigation showed an unexpected cause of this breakdown. The inspectors looking for scratches or bubbles, day after day, became so skilled in

detecting them that presently they were noticing minute defects with the same degree of effort that a novice would require to notice a large one. In other words, the standard was actually a shifting one, approaching high refinement and perfection in product, thus being psychological rather than physical. The remedy was found in a set of samples containing defects just under and just over the borderline with which comparisons could be readily made, combined with a recheck of a random percentage of both good and bad work, after each inspection.

Bench inspectors on repetitive work should be of temperament that develops willingness to follow strict instructions. They will be called upon to conform to rigid rules which require them to divide inspected product into three groups: (1) good, (2) clearly bad, and (3) doubtful. The latter class is reviewed by group leaders or foremen inspectors for acceptance or rejection.

Floor inspectors are required to exercise judgment, which must be backed by considerable technical experience. Among their duties are first-piece inspection, with authority to hold up the machine until it is properly adjusted, if the work is defective, and patrolling inspection which involves the right to stop any machine from which defective work is coming, in each case promptly notifying the shop foreman. Both tact and firmness, therefore, are necessary ingredients in the floor inspector's make-up.

TEACHING INSPECTORS.—The following points are summarized from G. S. Radford. As a management device for inspection economy, instruction of inspectors comes next after sampling to insure that no more work is done than is necessary. The instruction should not be casual, but should be combined with the work of one of the technical men on the chief inspector's staff. Even the most cursory use of motion study reveals large possibilities for saving time in inspection. Unskilled help should receive adequate instruction, not alone by teaching but also by providing accessible reference data, such as samples, large-scale drawings with gaging points distinctly marked, gage instruction cards, and so on. This educational work should begin as soon as the new inspector is employed.

REMUNERATION FOR INSPECTION WORK.—Inspection is usually regarded as belonging to the "expense" or "overhead" class of costs, and the tendency is to pare this cost as closely as possible, notwithstanding that in some operations high-grade qualifications are requisite in the personnel. To prevent the force from being permeated with chronic discontent, either a definite plan of **promotion at increasing pay,** or some form of **piecework,** may be introduced in some cases. Desirability of obtaining some check on the work of individuals, both as to quantity and quality of inspection done, offers the possibility of payment by results.

The inspector's hourly average of pieces inspected is the best indicator of his efficiency. Too sudden a rise in output in the case of a novice where a visual inspection embraces half a dozen or more points, is more unhealthy than a slow increase in output, as it indicates lack of care. The best control over an inspector's work is obtained by rechecking a certain portion of products which he passes and a portion of those he rejects. An experienced examiner can make this check on each inspector

once a week. The percentage of errors is recorded against the inspector, and, if good, may be used as the basis for a weekly or monthly grading list, with or without bonus payments, or, if bad, for private admonition including training to help him improve his record.

Where a piecework price is arranged for inspection work, which is chiefly practised where there is a continuous run of small parts, the recheck carries a penalizing effect, drastic reductions being made for any defective parts that have been accepted, and less heavy penalties being exacted for rejections that should not have been made. Piecework has been successfully applied in many plants, with large increases in output where the method has been based on a sound plan to give real control over the work. Many executives, however, are opposed to piecework in inspection and many consider that penalizing is undesirable.

Location and Layout

LOCATION.—Since some inspection is done on the floor in factory departments where work is in process, while other inspection is conducted in one or more central inspection areas, the location of inspection centers depends largely on which plan is followed. In a large plant there would be a central inspection headquarters for the chief inspector and a staff of experts, but there would be many inspection rooms, each equipped with instruments and facilities for checking the work in its immediate department or area. Floor inspectors would work under supervisors in the local inspection areas. In a small plant, the inspection department would have a central headquarters in which gages, instruments, etc., would be kept, and where certain inspection operations might be carried on. Floor inspectors usually would operate from this central point.

Factors in Location.—The whole problem is, first, one of accessibility to work areas served; second, whether inspection requires moving of parts into a central location because of the use of instruments or the greater speed that is possible with routine mass inspection; third, distances which work would have to be moved to reach inspection centers; fourth, time consumed and congestion brought about by the moving; and fifth, the possibility of moving inspection out to the work, as in product layout of equipment, to take advantage of straight-line methods of production.

Because it uses precision instruments, sometimes delicate in themselves, and always susceptible to injury from grit, dust, and sudden or great temperature variations, the inspection section should be located also where there is no vibration, air is clean, and light is plentiful. Air conditioning and temperature control should be provided when practical and the inspection area should be partitioned off from rest of shop. Daylight from the north is preferred to obviate strong sunlight and deep shadows. The fluorescent type of artificial lighting is being adopted in many plants because it gives more even distribution of white light with little heat.

LAYOUT.—Provision should be made for storage of incoming work, work in process of inspection, work accepted, work provisionally rejected

but subject to correction, and work rejected as scrap or salvageable for other uses. Ample room should be provided so that inspectors have the sense of unhampered movement. Height of tables, benches, stools, and chairs should be given careful consideration to avoid strain and fatigue. The height of table for a toolmaker's microscope may not be the best height for a large surface-plate upon which set-up of work and instruments used may require the taking of data at a higher level for ease of operation. Metal locker-type cabinets, with locks, should be provided for the storage of all portable instruments not in use, and glass cases or cloth covers should be furnished for heavy instruments permanently located. Every precaution should be taken to keep dust and grit from being tracked in or blown in through ventilators or windows. Floors should be covered with heavy linoleum. Tables and instrument stands, if of metal, should be topped with heavy green or brown linoleum or hard Masonite with well-waxed finish. Green is preferred as most restful to the eyes. Projection-type instruments should be screened against interference from lights outside instrument or screen. Provision should be made for degreasing or cleaning incoming work and greasing or otherwise protecting outgoing work.

Kinds of Inspection

METHODS IN USE.—There are a number of different kinds of inspection, each carried on because of the necessity for controlling quality of work in the best manner and detecting spoilage as early as possible, so that further loss can be prevented. Most plants inspect in several of the ways described, each method being applied for its own definite purposes.

Trial-Run Inspection.—This method calls for the inspection of the tool and testing it preliminary to a production run (Screw Machine Engineering). The tool may be checked against its drawing and specifications and may be found to be at variance with requirements. Then a trial run of a single piece will be made and this piece may be found to conform to tolerances. The toolmaker, from his experience, provided clearances not shown in the tool drawing or specifications, so that the work itself—the important factor—was correctly machined.

First-Piece Inspection.—Inspection under this plan consists in running a trial piece after a machine has been set up for a job, and checking the dimensions of the work against the drawing or sample. If the piece conforms to specification, the machine is turned over to the operator for the complete run. If not, the set-up man makes adjustments or changes the tool, until finally a good piece is obtained. Then the machine is released for production.

Pilot-Piece Inspection.—A further step beyond first-piece inspection is the running of a part through its entire sequence of operations on a series of machines set up for its production, especially in the case of product layout of equipment. Each tool and each machine set-up is thus tested and all defective tools are replaced and all wrong adjustments are corrected. When a good piece results from the cycle, the production line is released for actual operation.

Working Inspection.—Working inspection requires that the inspector shall check pieces, preferably at definite intervals, to make sure that the work is still being produced within tolerances. Tools wear or break and the operator may neglect to grind or replace them (unless the set-up man must do this), and machines may be sprung or adjustments may loosen. A systematic means is necessary for detecting and correcting these happenings, and working inspection is this means.

Automatic machinery requires that the same precautions be taken. Periodic inspections during the run are necessary. Many automatic machines are now equipped with automatic signals or stops which act to shut down the machine when tool or machine trouble develops. Punch presses, for example, may shut down when a punch breaks. Patrolling inspection, however, is advisable on all long runs to prevent accumulation of excessive spoilage due to tool wear, or the failure of an automatic stop to operate.

Key-Operation Inspection is done prior to, and immediately after, a critical or expensive operation, first, to avoid doing expensive work on a part already not up to standard and, second, to check the accuracy of critical work before proceeding with succeeding operations.

Sampling Inspection is performed on samples taken at random from lots of small parts. These samples are considered representative of the lot when it is not practical to inspect each piece. If the samples are unsatisfactory, the entire lot may be inspected, or it may be rejected. The number of pieces to sample depends on the work or part and its value and importance. Statistical methods have been developed to determine the sample quantities, but often past experience or careful judgment forms the basis for the decision.

Percentage Inspection.—Amount of inspection to be done is sometimes expressed in terms of percentage, 100% meaning each and every piece in the entire lot. Inspection may be in excess of 100%, meaning each part is subject to inspection as it passes from one operator to the next. Example: In assembly of time fuses for projectiles, each individual visually inspects each piece to see that the previous individual actually contributed his or her part before blindly adding the next component. In this way, each assembler in turn becomes an inspector checking the performance of the previous assembler, notwithstanding which a final assembly inspection consists of weighing the completed fuse on a sensitive balance which immediately indicates the omission of even the smallest component.

Preassembly Inspection is performed on finished parts as a final inspection prior to going to assembly.

Functional Inspection.—It is not sufficient that all components of an assembly pass preassembly inspection. Functional inspection after assembly checks the accuracy of assembly and assures that the assembly will function as intended. Example: Assembled breech blocks are fitted to a dummy cannon breech; if they function on the dummy they will function on any accepted cannon of the same size and type.

Efficiency Inspection.—This inspection is synonymous with the trial run of a completed ship, locomotive, turbo-generator, or other equip-

ment, for purposes of securing performance data to check against anticipated results.

Endurance Inspection is given to assemblies to determine how much use they can withstand and to locate weaknesses for correction. Examples: Telephone receiving sets, army rifles, etc.

Destructive Inspection is carried on to determine the ultimate resistance or effectiveness of the objects tested. It is regularly carried on at proving grounds to test guns, projectiles, and armor. Guns are sometimes tested to destruction to check the factor-of-safety calculations. A few shells are selected at random from a lot and fired to determine fragmentation or ability to penetrate armor. Sample armor plate is used as a target to determine resistance to penetration. This kind of inspection differs from other inspection in that the specimen tested is destroyed.

Product Inspection.—Product inspection is the art of applying tests, by the aid of measuring appliances, to observe whether a given item of product is within the specified limits of variability. The term **quality control** is more comprehensive than product inspection. Included in its concept are problems of design, specification, standardization, manufacturing facilities, and inspection. The end procedure in production control is inspection of the product to determine whether it conforms, or the degree to which it conforms, to established specifications and standards.

Tests Applied to Completed Mechanism.—After parts of a mechanism have been assembled, a final operating test or series of tests should be made, simulating maximum demands to be made on the mechanism after it is placed in service. Strength tests are in themselves the maximum limit. An armature will spin at twice its rated speed without bursting, or it will not; a derrick will lift the specified overload without permanent set, or it will not; a gun barrel will stand a heavy proof charge without bursting or bulging, or it will not. In such tests there is but one limit. But in many of the final tests and trials used to demonstrate standards of quality, the idea of permissible variations in quality (expressed in terms of limits) finds application, whether these tests are to be applied to the complete assembly or to some subassembly. Final tests must be made under a complete assembly or to some subassembly. These final tests must be made under conditions as near as possible to those which the mechanism will encounter in actual service. If service conditions cannot be duplicated, test conditions should always vary from service conditions in a known way and to the same degree, i.e., all mechanisms should be tested under like conditions.

PIECEWORK INSPECTION.—Work produced on a piecework basis requires much more inspection than work produced on a straight time basis. Operators anxious for maximum earnings become careless and a poorer quality of work is likely to result. A change-over from a time basis to a piecework basis generally requires an increase in inspection, the added cost of which, of course, must be more than offset by any advantages of the latter over the former system.

Inspection itself can be done on a piecework basis but the proper conditions must prevail—the object of inspection being primarily thoroughness, not quantity. Sloppy inspection, in the endeavor to make

high earnings, can cause untold delays and increased cost in assembly, if not subsequent malfunctioning of the finished product, with ultimate loss of customers and reputation. There have been cases, however, where piecework in inspection—with proper reinspection and checks, adequate rewards for good work, and penalties for poor work—has increased output and maintained high quality of inspection. Where safely possible, inspectors should be given the same opportunity as production workers to increase their earnings.

INSPECTION TICKETS.—In all kinds of inspection it is necessary to make reports on the work going through, to indicate the quantities of good parts available after each operation so that a sufficient number will arrive at assembly points or into storage. If rejections are high, the causes must be promptly located and corrected, and replacement orders may be required to make up shortages. Moreover, workmen are often paid only for the number of good pieces produced from an operation. A simple typical inspection ticket or report form is shown in Fig. 5.

INSPECTION TICKET

Model	Piece No.	Dept. No.	Date

Order No........ Emp. Name.......................... No........
Name of Piece..
....
Name of Operation..
No. of Operation...
No. Rejected {Stock Defective..................................
{Labor Defective..................................
No. Received......... No. Accepted......... No. Returned.........
Remarks ....
....
.........................Inspector

Fig. 5. Inspection Ticket

Patrolling and Centralized Inspection

DIFFERENCE BETWEEN THE TWO SYSTEMS.—Inspection to maintain control over quality of work in process is carried on under two main systems: (1) floor, or patrolling inspection, (2) centralized inspection. Under the floor or patrolling plan, inspection takes place at or near the machines. Under centralized inspection, parts are transported to a special enclosure or room, where, for particular work, careful measurements and tests may be applied free from disturbance, and, for routine mass inspection, special gages and other equipment can be set up to run the work through rapidly and at the same time remove all the rejects.

Floor inspection ranges from general patrolling supervision—keeping a general eye on work at machines—to close inspection and careful measurement of product at its place of production. Floor inspection is sometimes conducted from a cage or enclosed space intercalated in the line of work, product flowing through this space as though the area were one unit in a chain of machines.

CENTRALIZED INSPECTION.—Centralized inspection permits the employment of men and women of a lesser degree of skill and experience than are needed for floor inspection because supervision is always at hand. Division of labor is sometimes possible, leading to economy in inspecting processes. Elimination of disturbance and interference is facilitated. Understandings between workers and inspectors are less possible. It is therefore easier to hold quality to definite standards, and obtain a better flow of work. Highly centralized inspection becomes impracticable when large parts are in question, as in the manufacture of large machines, steam turbines, ships, and products of corresponding size. The latter must be inspected at the machine or in the work area. Where work is performed by highly skilled mechanics, less inspection is necessary. As the type of production tends toward small repetitive manufacturing, the desirability of central inspection makes itself felt.

When parts have to undergo many consecutive operations, it is important to discover faulty work as early as possible. Floor inspection at each stage may then supplement final inspection of processed parts in a central room.

Central inspection does not imply one inspection room only. The basic idea is separation of inspection from manufacturing. Several such rooms or cribs may therefore be employed, each located centrally in respect to the machines which it is to serve. It is usual to place the crib parallel with the flow of work through the shop.

Advantages and Disadvantages of Central Inspection.—The **advantages** of centralized inspection, combined with a storeroom for parts in process, are these, summarized from Radford:

1. Work can be stored in self-counting trays. A workman will come to the issuing window and obtain a box of parts, which he will machine and return. Inspection will show some good pieces and some bad, and the man will be credited accordingly. Collection of accurate data on production is thus facilitated, and can be used for checking piece payments. Losses from misplaced, stolen, or destroyed parts will be at a minimum.
2. Only one box of parts, that being worked on, will be at the machine. The result is a clean, clear shop.
3. Systematic arrangement of all parts in flow makes it possible to check on movements of materials, particularly when schedules are in arrear.
4. Control of quality is more certain. Work of inspectors is more easily supervised. Less skilled workers may be employed, reducing labor costs. Decisions on doubtful cases may be made at once by an authority. Custody of work in process is well centralized. Each such station can be furnished with standard samples, lists of gages to be applied, and all other pertinent data, to avoid running about for reference.

5. Fixed and automatic inspection devices make mass inspection possible and lower costs.
6. Accurate inspection with delicate instruments can be done under controlled conditions. Such instruments cannot be taken into the shop.
7. Fewer gages and special fixtures are required because the same tools can be used for inspection of a number of parts from different departments.

There are certain **disadvantages** under centralized inspection, mainly those which constitute the advantages of floor inspection. These disadvantages are:

1. Considerable spoiled work may result from failure to detect machining errors in time.
2. Aid to the shop comes after a job is done, not in time to correct the trouble on the spot.
3. More materials handling is required.
4. Banks of work in process may develop in the inspection department, thus increasing the total amount under manufacturing.
5. Unless the inspection room is in the line of flow, there is often a break in the plan of product layout for straight-line manufacture.
6. Delays and piling up of work sometimes cause the inspection room to be a bottleneck in the production cycle.
7. Routing, scheduling, and dispatching through inspection increase the work of production control.

Advantages and Disadvantages of Floor Inspection.—Floor inspection has certain **advantages**, among which the following are important:

1. If inspection is done on a systematic basis, errors will often be caught in time to prevent spoilage of large lots of parts.
2. Difficulties in the doing of work come to the attention of the inspector, who can aid in clearing up trouble when it arises.
3. Materials handling is reduced because work does not have to be moved to and from a central inspection room.
4. Some reduction can be made in the amount of work in process.
5. The plan fits in well with product layout and mass production, keeping work flowing.
6. Bottlenecks and delays, which often occur at inspection rooms, are obviated.
7. Routing, scheduling and dispatching parts through inspection rooms are eliminated. Floor inspector, however, can route parts through a central inspection department when he finds more thorough inspection is indicated.

The **disadvantages** of floor inspection are to a large extent the antitheses of those favoring central inspection. They arise from the following conditions or causes:

1. Some condition where it is difficult to get the count of good and bad pieces.
2. More work is piled up at machines. The worker has his completed work awaiting inspection while he is doing his next lot.
3. Presence of large quantities of work on the floor complicates the timing of the actual moving to keep work flowing.
4. It is difficult to control quality of work. Inspectors cannot be readily checked. They may become careless, or may play favorites with certain workers. More highly skilled inspectors are required, thus raising labor costs. Delays occur in deciding doubtful cases. Work in process is scattered, from the inspector's standpoint, and he may

lose track of some lots and delay their removal. The inspectors must carry their own cases of instruments and samples with them, or else go to their offices when these facilities are needed.

5. Where inspection of a highly accurate kind on delicate instruments cannot be performed. Sometimes such instruments cannot be taken into the shop, and shop conditions (dust, vibration, etc.) would prevent close inspection even if the instruments could be moved.

COMBINED SYSTEM.—While either floor inspection or centralized inspection may predominate in a plant because of the nature of work, shop conditions, and other factors, in practically every case the two plans will be found combined. There will be large work, which will require floor inspection. Patrolling inspectors are often necessary to keep operations flowing and clear up troubles on the spot. Checks of this kind often stop spoilage of work almost as soon as it begins. Costs and inconveniences of moving work, and the low value of many individual pieces which are merely sampled, may make a floor check the most economical procedure for many operations.

On the other hand, the need for accurate inspection of certain parts or subassemblies may require that they be moved to a central inspection department. The advantages of automatic inspection devices, to routine inspection at high speed by experienced inspectors, the lesser skill required, and the low costs which these conditions bring about, encourage doing as much of the work as possible in central rooms or cages. Each inspection operation should be studied in reference to its nature and importance and its relation to other work, and the place of inspection can then be determined to bring about the desired control of quality at the most reasonable cost. The total result will be the best program of inspection for maintaining production standards, and the lowest over-all cost for inspection, which, although vital and indispensable, is not a directly productive operation.

Nature and Extent of Inspections

CONDITIONS INDICATING EXTENSIVE INSPECTION.—Conditions indicating the desirability of an extensive development of the inspection function have been enumerated by Babcock as follows:

1. Product demands frequent and thorough inspection, as when great accuracy is required.
2. Models are changed with frequency, as in a swiftly advancing art.
3. Labor is unskilled or rapidly changing.
4. Quality standards are being raised.
5. Considerable judgment must be used because standards are being shifted or have not been reduced to a definitely measurable basis.

E. W. Ritter, Vice-President and Director of Manufacture and Engineering of the Corning Glass Works, considers inspection to be specifically necessary where the item to be tested has many parameters and limits, some of which are critical.

Every industry has its peculiar problems, not only in regard to inspection of product at various stages but also in relation to the closely allied work of maintaining satisfactory conditions. Upkeep of tools and gages in machine-shop work can be compared in some degree with the ceaseless scrutiny of temperatures, pressures, end-points, and other con-

trolling conditions of processing in nonmachine-shop industries. More than any other department of the factory organization, an inspection service must be specially designed and adapted to the precise circumstances in the particular plant.

UNNECESSARY INSPECTION.—Another feature which requires attention is elimination of unnecessary inspection. Many operations require no inspection whatever. Sometimes fixtures on succeeding operations can be so designed as to serve as gages to detect a missing or incomplete operation. Inspection, in other cases, may be dropped for the first operations in a series when a check at some later key operation can pass the work of several preceding operations. This plan is one of the economics attending product layout whereby all the work on a part is done on machines arranged together in sequence of operations. Similarly, and especially in the case of floor inspection, if the first several parts inspected are found to be right, inspection of the remainder of the lot may be waived. This procedure is safer, however, if a few of the last parts made are inspected in the same way. In other cases parts may be of such minor importance and slight cost as to make it advisable to drop inspection in favor of the more certain test of their acceptability for use in the assembling department. This condition is true of most small screws and minor screw-machine products.

INFORMATION FROM INSPECTION PROCEDURE.—One of greatest benefits of inspection service comes from its power to bring promptly to the attention of management information as to the true state of manufacturing operations so that faults and inefficiencies in processing may be corrected. The foreman-inspector of each shop is close to what is going on in that shop, and is likely to be unbiased because he is an observer rather than a producer. Thus he is excellently situated to locate manufacturing troubles, frequently to isolate their causes, and sometimes to offer suggestions for their cure.

Production difficulties ordinarily appear in the form of too great losses in spoilage, or through slowing down of production at some operation, thus creating a bottleneck or a partial choke-point. It is essential to correct the difficulty as soon as possible, but to do this it is necessary to develop and bring to light the true causes, which usually are due to poor materials, inadequate or poorly maintained machinery and tools, unsuitable inspection devices, careless set-up of work, untrained or incapable workers, or ineffective supervision and control.

Trouble Reports.—A useful device for the prompt collection of trouble data in regard to the above or other causes may be secured by providing a printed form or "trouble report" to be made out and sent by foremen-inspectors of shops to the chief inspector, who will transmit such facts as seem worth attention to the department that should correct the trouble—management being furnished with a copy. A detailed list of the usual sources of trouble (tools, gages, material, and so on) may be included for convenience, but the essential idea is to make the foreman-inspector feel responsibility for promptly reporting the full facts and nothing but facts. Hence he is required to state either that he "knows" or that he merely "thinks" trouble is due to the cause stated in his report. For the trouble report to be used successfully, the foreman-inspector must have confidence in the judgment, fairness, and courage

of his chief—he must feel sure that he will be backed up if he is right. Further, the management should make quite clear that it is looking for facts to cure troubles, and not to find someone to blame. There is no surer way to put a premium on the concealment of facts than by trying to fix blame on an individual, nor does blaming someone help to cure the trouble. Presumably, each individual holds his job because he is the best available man for the position. If he is not, the management will know it much sooner if he and his associates are not continually placed in the position of being called upon to make excuses (G. S. Radford).

SALVAGE OR REPLACEMENT OF DEFECTIVE PARTS.— When work fails to pass inspection, three courses are open: (1) the item may be worked over again to eliminate the defect, (2) it may be converted to some other purpose, or (3) it may be condemned altogether and sent to the scrap heap. If it is not fully brought up to standard by reworking, it may be sold for a second-grade product. In repetition work, many plants have salvage departments, wherein defective work is examined and when possible rectified for productive purposes. If it is not possible to refit the item for use, the next lot going through should be made larger to replace the pieces so withdrawn. In nonrepetitive

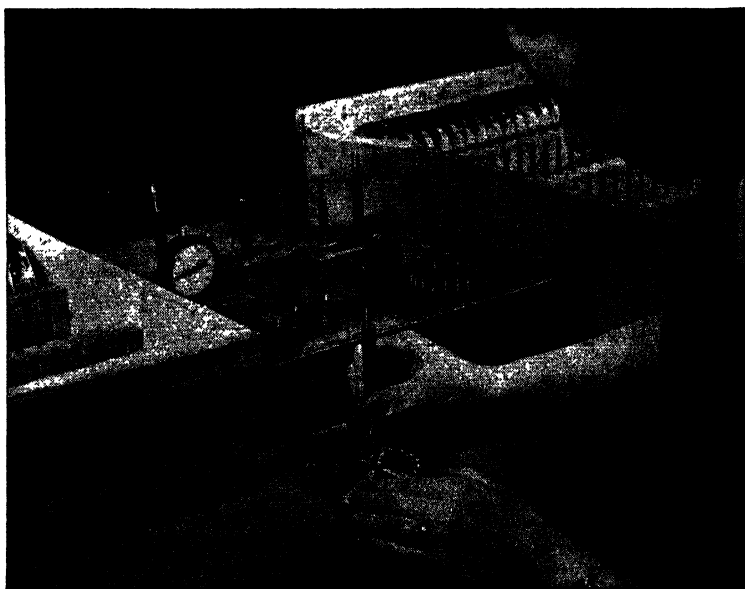



Fig. 6. Bench Inspectors Are Supplied with Boxes in Which Gages for Parts to Be Inspected Are Arranged in Order of Use

(Aero Digest)

work, spoilage of one piece usually entails its remanufacture, from casting or forging up. A carefully organized procedure is advisable, therefore, to make good the loss, including prompt issue of replacement orders for all materials and operations, and their incorporation in machine-loading and progress schedules and route sheets. Spoilage and replacements, being exceptions to a well-ordered routine, require a standard routine of their own if delays and confusion are to be avoided.

Facilitating Inspection Work

GAGES SUPPLIED IN BOXES.—Rapidity, convenience, protection of gages, and high accuracy in inspection have become paramount factors in many lines of work. Aids to these objectives are typified by methods adopted in the Nash-Kelvinator Corporation (Aero Digest, vol. 42). Operators in the manufacturing departments who must check up on dimensions of work are provided with specially fitted boxes containing all the necessary gages, arranged in the order of use, and held in suitable receptacles such as holes, slots, and recesses. The boxes are numbered to correspond with the operations checked. The simplified

Fig. 7. Gages Mounted on Plywood Boards for a Sequence of Inspection Measurements on a Part

(Aero Digest)

drawings from which the machine operators work list the tools required and the gages used in inspection.

Bench inspectors are also supplied with fitted gage boxes, as shown in Fig. 6, the work being so planned that the gaging operations of all inspectors will take about the same amount of time. The schedules thus set up determine the number of gages assigned to each inspector. When indicator gages are provided, masters for setting the indicators are built in and dials are marked in red to show limits.

MOUNTING GAGES ON BOARDS.—A further improvement in the case of small and easily handled parts was the permanent mounting of gages on heavy plywood boards, according to sequence of inspection operations. The instruments are so spaced that the parts can be positioned conveniently as they are put through each step in the inspection. An inspection board of this kind is shown in Fig. 7. The two rows of labeled boxes in this illustration are for the segregation of rejects—the top row for oversize and the bottom row for undersize parts—and the separation in each row is by dimension being tested. The operation producing excessive rejects can thus be quickly determined.

Data entered on rejection tags, which are put on the fronts of the boxes, or on separate pieces, reduce the number of inspection records required. The data are part name, part number, date, shift number, inspector's name, inspection point, and disposal—special, repair in department, hold, or scrap. Outline drawings of the parts on the tags allow the location of the errors to be marked.

Precision Measurement Standards

PRECISION VS. LINE MEASUREMENT.—By precision measurement is meant taking measurement to an accuracy of not less than one-thousandth of an inch of the exact dimension. Instruments which measure to that or a greater degree of accuracy are termed **precision measurement instruments** whereas those measuring to within the hundredth part of an inch—or coarser—are known as **line measurement instruments.** Some precision instruments are capable of an accuracy of a few millionths of an inch. Such close measurements are seriously affected by temperature changes so that, under temperatures a few degrees above or below those at which the precise measurements were originally taken, it is impossible to obtain the same readings, because of expansion or contraction of the specimens accordingly.

INTERNATIONAL STANDARD FOR MEASUREMENT.—It is obvious, therefore, that for purposes of comparison and consistency, some standard temperature at which precise measurements should be made, or to which they can be reduced if made at other temperatures, is essential. During the First World War many difficulties arose in producing goods for international trade because, although temperature standards had been independently adopted by various countries, there was no international standard. In Great Britain the standard was 62° F., in France 32° F., in Germany 58° F., in the United States 68° F., and so on. After that war an international standard was accepted at 68° F.;

or its equivalent of 20° C. This, however, did not solve the international measurement problem because there yet remained no internationally accepted factor for converting English measurement units into metric units and vice-versa. Through the efforts of the International Standards Association the standard of one inch equals 25.4 millimeters was adopted by the United States, France, Germany, Japan, Denmark, Finland, and several other countries, as the conversion factor. We now have an international standard for the conversion of measurements and an international standard of temperature at which to make them. Thus, in times of warfare, it is possible for allies to cooperate in the production of munitions each for the other according to their best abilities. In peace time, the manufacture of machine tools and machinery for export now offers no greater problem than for home consumption, as far as measurements are concerned. Likewise, standardization of machinery parts, fittings, etc., has been simplified by the adoption of standards, as in screw threads, and in some cases even in design, as in American Gage Design Standards.

Emphasis cannot be too strongly put upon the importance of designers' referring to standards, where standards exist, for the elements of their designs. Lists and copies of many important standards are obtainable through the American Standards Association.

Fundamentals in Inspection

PRINCIPLES OF INSPECTION.—Quality of the desired degree must necessarily be worked into the product by control of processes. Inspection cannot perform this task; it does not make goods but only passes on them. Responsibility for production of standard quality rests on those responsible for manufacturing. Inspection checks the achievement; it is measurement plus judgment.

Failure to attain expected standards of quality occurs (1) from faulty engineering or design, or (2) from failure of the manufacturing department to give effect to design. If inspection is subordinate to engineering, design defects will tend to be concealed. If it is subordinate to manufacturing, poor methods of production will fail to show up, and quality will slip, probably all along the line.

METHODS BASED ON OBJECTIVES.—Inspection methods, in general, are based upon the objectives sought, such as hardness, surface finish, measurement, dielectric properties, etc., and in each case call for the application of appropriate standards. Colors may be graded in terms of intensity of color or by stipulating the amount of primary colors plus black and white. Textiles, paper, and metals have standards of strength and their physical properties are capable of measurement. Inspection may also require determining constituents of materials and critical points in processing. The proportion of contained elements is determined by chemical analysis. Internal structure, cavities, flaws, and variations in homogeneity are revealed by the X ray. "End points," or the stage where opposing chemical forces are in equilibrium, are determinable by use of the hydrogen electrode. Other characteristics and properties are discovered through the microscope, as in metallographic studies. Linear and angular measurements are obtained by use of

scales, micrometers and verniers, protractors, comparators, and a host of special measurement instruments. All the foregoing and many others are tools for inspection the applications of which must be definite and specific, that is, reduced to simple yes-or-no tests. Usually but one property of the material is studied at any one time. The question to be answered and the terms and limits of the answer must be carefully predetermined.

Inspection Procedure.—Procedures in the various methods of inspection are quite definitely set forth in fullest detail in handbooks and standards promulgated or sponsored by the various technical societies in question and the American Standards Association, and in many texts. Descriptions of apparatus and instruments are readily available in trade catalogs and special texts, affording the inspector means for predetermining the suitability of a particular instrument or selecting a more suitable instrument. The scope of this Section is to give pertinent information not found in such references, and particularly as applying in connection with machine-shop practice.

DESIGN.—Between design and execution of a given piece of work, every opportunity exists for difference of opinion regarding permissible variations. The designer will tend naturally to specification of limits as fine as possible. The production man, knowing that precision under ordinary conditions is costly, will tend toward demanding looser limits. The need for compromise under expert guidance is evident. An ideal standard prescribes no variations, but the nearer the approach to this dead theoretical accuracy, the greater the difficulties in manufacturing and the higher the cost. In making an objective for a great observatory telescope, a very close approach to absolute accuracy is essential, but such work requires months of the most skilful and patient application, quite outside the range of any commercial production. Beginning with an ideal design, the first step toward realization in the usual case is to determine practicable variation limits, having due regard (1) to the purposes to be secured by high accuracy, (2) to its cost, and (3) to the method of manufacture.

INSPECTION STANDARDS.—Inspection standards for raw materials are first considered. Selection of material is dependent partly on the use to be made of it, and partly on the nature of the processes through which it must go. Much study has been given to this subject. Various societies and public bodies have issued standard specifications for various kinds and grades of material and these are largely used. Permissible variations in the chemical constituents of material (e.g., metals) and limiting conditions for important physical characteristics are given.

Inspection standards for work in process may be classified under four heads: (1) in relation to physical condition or properties of material, (2) relating to degrees of finish, (3) relating to form and dimension, (4) chemical, and (5) functional or performance.

Inspection of **condition of product** after any given process may have reference to either (1) result of the process, or (2) fitness of the product for an ensuing process. For example, after heat treatment auto gears may be subjected to Rockwell, Brinnell, and scleroscope tests to check hardness of finished product. Heat treatment of such gears is

divided into five steps: normalizing for forging strains, annealing for rough machining, carbonizing, heating to refire the core, and finally hardening, quenching, and drawing of the finished product. Absolute control over heat treatment is maintained by taking test pieces from time to time, and making microphotographs after each step, to check grain structure.

Control is maintained by continuous observation and recording of pressures, temperatures, and other processing conditions.

Inspection standards in relation to **finishes** have been necessarily less exact due to former absence of standards. Such elements as smoothness, hue, shade or tint, polish, mattness, etc., could rarely be reduced to definite tests. In the absence of measurement devices and standards, much depended on the personal equation, comparison with sample being the principal reliance. Recent developments have provided a profilometer, a portable sensitive electrical instrument which magnifies the surface irregularities making it possible to discern variations as coarse as .001-in. and as fine as .000001-in. Also a set of visual standards, consisting of a set of steel blocks each of a different degree of finish, has recently been made available. With these as standards visual comparison with the surface on work readily shows how the finish of the latter compares with the standard selected. Meshed gears, screw threads, and other mechanical units may be illuminated with a powerful light and a many-times-magnified image thrown on a screen. Visual inspection for contour, smoothness, and finish is then reinforced.

Most machine-shop, engineering, and mechanical industries rely largely on standards of **form and dimension** to maintain control of quality. Interchangeable manufacturing is based on such standards. In any given piece, limits of variation may be more important in one direction than another. Outside surfaces may vary within wide limits, but surfaces that must come together or "fit" must have carefully prescribed limits of variation. Naturally, these limits are not the same for all surfaces even when they are to be fitted together. Limits in watch manufacture are evidently not the same as those used in making agricultural machinery.

TERMINOLOGY.—So that there may be uniformity of understanding as to the meaning of terms most used in shop inspections a few terms are herein defined. Care should be exercised in their use lest confusion result. "Tolerance," for example, is not the same as "limit," and "allowance" is not synonymous with "clearance."

Limits and Tolerances.—It is obviously impracticable to make all work conform to exact dimensions. The machinist must have some leeway within which to work, some range of dimensions within which a part so made will function satisfactorily. Therefore if a piece is required to be 2 in. but can vary ever so slightly and still function properly, that variation should be granted to the workman to keep within. Thus if the part can be .003 in. smaller or .002 in. larger than the basic dimension of 2 in. then the drawing for that dimension might show some such dimensioning as: $2.000 \begin{array}{l} +.002 \\ -.003 \end{array}$ which means any piece not larger than 2.002 in, or smaller than 1.997 in. will satisfactorily fill the requirements. Thus a leeway or **tolerance** of .005 in (from .002 above to .003 below) is provided within which the part can be produced quicker and cheaper than if held

to the basic 2-in. size. The tolerance is therefore the range in permissible dimension between the **upper limit** and the **lower limit**, these limits being the dimensions above or below which a part will not be acceptable.

Allowance.—The term "allowance" is loosely used in the shop, as is the case with many terms. It is the intended difference between the maximum dimension of one mating part, such as a bearing, and the minimum dimension of the other mating part such as the shaft. (See Fig. 8.)

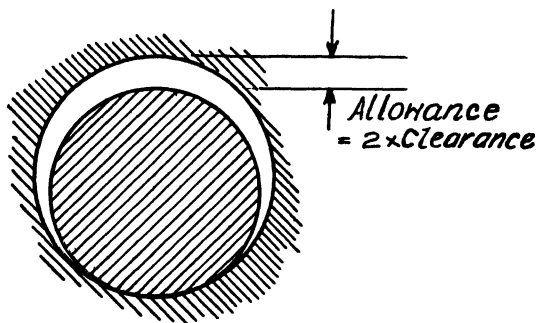



Fig. 8. Diagram Illustrating Allowance

Clearance.—Clearance is one-half of allowance, is uniform on all sides, and should not be confused with allowance, which is twice the clearance. A shaft at rest makes contact with the bottom of a bearing. When in motion, theoretically, at least, the shaft centers itself coincident with the center of the bearing and rides on the oil film carried evenly all around beween the shaft and the bearing. When speaking of clearance, one means clearance all around as shown in Fig. 9.

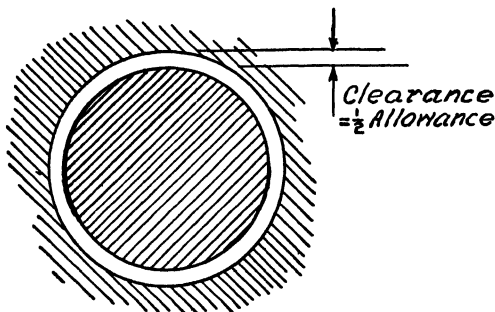



Fig. 9. Diagram Illustrating Clearance

Working Standards.—Limits and tolerances, when worked out, are inscribed on working drawings. In large work, and where the number in a lot is small, blueprints suffice for all instructions. In quantity production, specially designed auxiliary equipment is usually required for economical manufacturing. Precision in dimension is practically transferred to these devices, and work is checked simply by the use of gages of fixed dimensions (upper and lower limits). Inspection measurement is confined, therefore, to a series of yes-or-no questions.

Fits.—In order that two pieces shall satisfactorily function together, as a shaft in a journal, there must first be established a criterion as to what constitutes "satisfactory." A shaft may fit its bearing tightly and not function properly or may fit loosely and not function properly. Under another set of conditions each shaft may perform exactly as desired and be very satisfactory. The conditions to be fulfilled govern the degree of "fit" desired between the two components. To provide uniformity throughout the industry a **classification of fits** has been adopted which satisfies most conditions. These, as recommended by the American Standards Association, are as follows:

Class I. Loose fit, in which maximum dimensional variation is provided between shaft and hole.

Class II. Free fit, providing for a more restricted dimensional variation than for Class I.

Class III. Medium fit, providing a still more restricted dimensional variation than for Class II. Used where parts must work freely and yet not impart evidence of freedom to other parts, as in machine-tool operations where looseness of assembly and functioning would be reflected in the production of unacceptable work, because a machine tool will not produce work of accuracy greater than built into itself.

Class IV. Snug fit, in which mating dimensions are reduced to a minimum but still permit the parts to function. This fit provides no "play" between parts and is used for machine tools of "precision" quality.

Class V. Wringing fit, in which mating dimensions are so closely held as to provide no clearance between parts, hence metal-to-metal contact. Because of the closeness of mating dimensions, fitting of such parts is principally by selection rather than by interchangeable system.

Class VI. Tight fit, used where mating parts function as one unit, such as tight pulleys on a shaft requiring slight pressure to assemble. Pulley rotates with shaft, not around shaft.

Class VII. Medium-forced fit requires greater pressure to assemble than for Class VI and is used for permanent assemblies not requiring transmission of great power from one component to the other, as in Class VIII.

Class VIII. Heavy forced and shrink fit, a class of fit such as employed to assemble a flywheel onto a crankshaft where the flywheel is used as a pulley to transmit great power by belt; also to assemble car wheels to axles, etc. If the pressure to apply would result in exceeding the elastic limit of the material in the component, the parts can be fitted in the following manner: the shaft can be cooled to shrink it, and the other component, such as a flywheel, can be heated to expand it so that it will slip easily over the shaft. Upon regaining normal temperature both components seize as one unit. This shrinkage system is characteristic of assembly of cannon on the "built-up" principle whereby the cannon tube is reinforced towards the breech by successive tubes concentrically shrunk on.

For each classification of fit there are definite established tolerances according to size of hole or shaft. Reference should be made to such standard tables of tolerances for fits in designing such mating parts.

Instruments

SELECTION.—Selection of inspection department instruments is dependent entirely upon the nature of inspection and the work involved. Instruments required for one inspection section may not be required in another. However, if many gages are to be inspected to maintain their accuracy, a separate laboratory should be provided exclusively for the purpose.

GAGE-CHECKING LABORATORY EQUIPMENT.—The selection of the necessary instruments for properly equipping a gage-checking laboratory is dependent upon whether the gages to be checked are limited to a few types or extend to a wide variety of types. For an extensive installation the list given in Fig. 10 will be found equal to almost all requirements, though, for a small laboratory, selection from this list should be made according to probable requirements, taking into consideration kinds and size-ranges of gages to be checked.

MARKING AND RECORDING OF GAGES.—Gages which have been inspected and accepted should be marked with identification letter and number, the letter to identify laboratory acceptance of gage and the number to identify each individual gage. The inspector should prepare data for a **gage record card, such as Fig. 11, one for each gage,** bearing the following information:

1. Gage letter and number.
2. Date of inspection and acceptance.
3. Name and drawing number of assembled item for which the gage is intended, such as Diesel, 6-cyl. Model B; Point Detonating Fuse M 30; etc.
4. Name, drawing number and piecemark of particular component part to which gage applies, such as Cylinder Sleeve; Body; etc.
5. Functioning of gage, such as Inside Diameter, Length Over-all, etc.
6. Type of gage, such as Thread Plug; Plain Ring; etc.
7. Gage drawing number.
8. Required sizes, lead, angle, etc., with permissible tolerances as required by component drawing.
9. Actual size as found by measurement of gage.
10. Location in gage storage compartment.
11. If some part of gage does not meet gage drawing requirements, but does not affect functioning of gage, the chief inspector may order acceptance, in which case deviation from gage drawing must be noted on gage record card.

CARE OF GAGES.—After classification of the gages and preparation of the record cards, gages should be cleaned and protected from rust by a heavy coating of moisture- and acid-free grease, and then wrapped and stored in the proper location, notation being made on the card of the rack and bin number, and care being exercised to place the gages exactly as noted. Every portable instrument should have a definite place on shelving in cabinets, which place should be marked or labeled with the

1 Set Accessories, precision gage blocks #47, Johansson or equal
1 Ea. Attachment for measuring small screw threads on Pratt & Whitney machine
1 Ea. Attachment for measuring large screw threads on Pratt & Whitney machine
1 Set Blocks, precision, Laboratory #1AA, accuracy, (81 blocks) rectangular in shape
1 Set Blocks, precision, #1A (81 blocks) rectangular in shape
1 Set Blocks, precision, #4A (28 blocks) thin, rectangular in shape
1 Set Blocks, precision, #10A (8 long blocks) rectangular in shape
1 Set Blocks, precision, Angle Set #97, Johansson or equal
1 Pr. Blocks, V, 1⅜" x 1⅜" x 1⅛"
1 Pr. Blocks, V, 2⅜" x 2½" x 1⅞"
1 Pr. Blocks, V, 4" x 2⅞" x 2⅞"
1 Set Buttons, Toolmakers, .300
1 Set Buttons, Toolmakers, .400
1 Set Buttons, Toolmakers, .500
1 Set Buttons, Toolmakers, 1.00
1 Ea. Box with glass top, with light inside for comparing gages with master check
24 Ea. Balls, hardened steel, assorted sizes
1 Ea. Caliper, Vernier, 6"
1 Ea. Caliper, Vernier, 12"
1 Ea. Caliper, Vernier, 24"
1 Ea. Center Bench, with indicator bracket and sine bar attachment
4 Ea. Clamps, "C," 1¾", Williams Co. or equal
2 Ea. Clamps, Toolmakers, ⅝"
2 Ea. Clamps, Toolmakers, 1"
2 Ea. Clamps, Toolmakers, 1½"
2 Ea. Clamps, Toolmakers, 2"
2 Ea. Clamps, Toolmakers, 2½"
2 Ea. Clamps, Toolmakers, 3½"
1 Ea. Comparator, direct reading dial, 10,000 graduations with center and V-Block attachment, Federal #100 or equal
1 Ea. Comparator, Vertical, direct-scale measurement, 4" capacity
1 Ea. Comparator, Interference, for the absolute and relative measurement of precision gage blocks
1 Set Disks, Reference, ¼" to 3", varying by 1/16"
1 Ea. Demagnetizer
1 Ea. Etchograph, for marking gages
1 Ea. Etching Machine
1 Ea. Fixture, precision, circular dividing, for checking circular graduations
1 Ea. Fixture, gage holding
1 Ea. Fixture, Sine Bar, 5"
1 Ea. Fixture, Sine Bar, 10"
1 Set Figures and Letters, 3/32"
1 Set Figures and Letters, ⅛"
1 Ea. Flat, Toolmakers, 5" dia. at least
1 Ea. Gage, Depth, Vernier, 6" Blade
1 Ea. Gage, Depth, Vernier, 12" Blade
1 Ea. Gage, Height, Vernier, 10" with depth attachment
1 Ea. Gage, Height, Vernier, 18" with depth attachment
1 Ea. Gage, Visual ten-millionths graduation, Sheffield or equal
1 Ea. Gage, Dial Depth, Dial graduated in 10,000, #14, Standard or equal
1 Set Gages, Parallel, Taper, covering all dimensions ¼" to 1"
1 Ea. Gage, Surface, Base, 2¼" x 1½" hardened, 4" spindle
1 Ea. Gage, Surface, Base, 3½" x 2½" hardened, 9" and 12" spindles
1 Ea. Gage, Screw Pitch, International, 17 pitches, 5 mm. to 7 mm.
1 Ea. Gage, Screw Pitch, 51 pitches, 4 to 84 pitches
1 Ea. Gage, Screw Pitch, Whitworth Standard, 24 pitches, 4 to 48 pitches
1 Ea. Gage, Thickness, 9 Blades, .0015, .002, .003, .004, .006, .008, .010, .012 and .015"
1 Ea. Gage, Thickness, 22 Blades, .004 to .025 by thousandths
1 Ea. Gage, Fillet and Radius, radii 9/32" to 33/64"
1 Ea. Glass, Jewelers
1 Ea. Glass, Magnifying, Double Lens
1 Ea. Indicator, Deming
1 Ea. Indicator, Last Word
1 Ea. Indicator, Dial, 10,000 graduations with Universal back, B. C. Ames or equal

FIG. 10. Equipment for a

1 Ea. Indicator, Dial Test, #730, Brown & Sharpe or equal with internal, universal and clamp attachments
2 Ea. Irons, Universal Right Angle, 3¼" x 4" x 5"
2 Ea. Irons, Universal Right Angle, 5½" x 7" x 10"
2 Ea. Irons, Angle slotted, 6" x 6" x 8"
2 Ea. Knees, Toolmakers, 2¼" x 3" x 4"
1 Ea. Knee, Toolmakers, Adjustable
1 Ea. Lamp, Wide Field, complete with stand and 15-watt bulb
1 Ea. Level, Precision
1 Ea. Light Wave Equipment, Van Keuren or equal
1 Ea. Machine, Measuring, 48", with pressure tailstock, elevating table, length support, master bar, microscope, pedestal and service kit
1 Ea. Machine, Comparator and Measuring, Pedestal type
1 Ea. Micrometer, Super Bench with pressure tailstock, elevating table, 8-1" dia. disks and service kit, Pratt & Whitney or equal
13 Ea. Micrometer, Super Internal with Master Reference Rings, ranging from .500" to 1.00" John Bath or equal
1 Set Micrometers, Internal, Tubular, Range 2" to 12"
1 Set Micrometers, Internal,Tubular, Range 12" to 22"
1 Ea. Micrometer, Caliper, Inside, Range .200" to 1.00", #250, Brown & Sharpe or equal
1 Ea. Micrometer, Caliper, Inside, Range .500" to 1.5", #252, Brown & Sharpe or equal
1 Ea. Micrometer, Caliper, Inside, Range 1.00" to 2.00", #254, Brown & Sharpe or equal
1 Ea. Micrometer, Caliper, Outside, Range 0" to 1.00" with rounded anvil and spindle
1 Ea. Micrometer, Caliper, Outside, Range 0" to 2.00"
1 Set Micrometer, Caliper, Outside, 1", 2", 3", 4", 5", 6"
1 Ea. Micrometer, Caliper, Outside, Range 6" to 7"
1 Ea. Micrometer, Caliper, Outside, Range 7" to 8"
Note: All outside micrometer calipers, to be equipped with ratchet stop, locknut and standard. To be graduated in ten-thousandths. Should be selected for accuracy. To be furnished in leather case.
1 Ea. Outside Micrometer Caliper, Indicating, Range 0" to 1.00", Zeiss or equal
1 Ea. Outside Micrometer Caliper, Indicating, Range 1" to 2", Zeiss or equal
1 Ea. Outside Micrometer Caliper, Indicating, Range 2" to 3", Zeiss or equal
1 Ea. Outside Micrometer Caliper, Indicating, Range 3" to 4", Zeiss or equal
1 Ea. Outside Micrometer Caliper, Indicating, Range 4" to 5", Zeiss or equal
1 Ea. Outside Micrometer Caliper, Indicating, Range 5" to 6", Zeiss or equal
1 Ea. Microscope, Toolmakers
1 Ea. Microscope, Inspection, Wide Field, Binocular, with revolving drum nose-piece and stand
1 Ea. Magnifier, Rectangular, with adjustable stand
1 Ea. Optical Dividing Head with base and tailstock
1 Ea. Optimeter, Horizontal, with internal measuring attachment
1 Ea. Optimeter, Ultra, 10" capacity, Zeiss or equal
2 Ea. Oil Stones, fine
2 Ea. Parallels, steel hardened, ground and lapped, .100 x .300 x 3.00"
2 Ea. Parallels, steel hardened, ground and lapped, 5/16" x ¼"
2 Ea. Parallels, steel hardened, ground and lapped, ⅜" x 5/16"
2 Ea. Parallels, steel hardened, ground and lapped, ½" x ¼"
2 Ea. Parallels, steel hardened, ground and lapped, ⅝" x 5/16"
2 Ea. Parallels, steel hardened, ground and lapped, ¾" x ⅜"
2 Ea. Parallels, steel hardened, ground and lapped, ⅞" x 7/16"
2 Ea. Parallels, steel hardened, ground and lapped, 1" x ½"
2 Ea. Parallels, steel hardened, ground and lapped, 1⅛" x ⅝"
2 Ea. Parallels, steel hardened, ground and lapped, 1¼" x ⅝"
2 Ea. Parallels, steel hardened, ground and lapped, 1½" x ¾"
2 Ea. Parallels, steel hardened, ground and lapped, 1¾" x ⅞"
2 Ea. Parallels, steel hardened, ground and lapped, 2" x 1"
2 Ea. Parallels, Box, 6" x 4" x 4"
2 Parallels, Box, 6" x 4" x 6"
2 Ea. Parallels, Box, 12" x 5" x 8"
1 Ea. Plate, Angle, Adjustable, with sine bar attachment and vernier to read in 1 degree
1 Ea. Plate, Surface, 8" x 10", planed and hand scraped, with cover
1 Ea. Plate, Surface, 13" x 15", planed and hand scraped, with cover
1 Ea. Plate, Surface, 18" x 36", planed and hand scraped, with cover

1 Ea. Plate, Lapping, 12" x 12"
1 Ea. Plug, Threaded, 1⅛" dia., 2½" long with taper flat on two sides, hardened, accurately ground and lapped, for checking roundness of threaded measuring wires
1 Ea. Protractor, Universal Bevel, with acute angle attachment with 6" and 12" blade, in case
1 Ea. Protractor, Optical Level
1 Ea. Roll, .750" dia., 1¼" long, one side flat, hardened and accurately ground and lapped for measuring diameters of thread measuring wires
2 Ea. Rolls, Measuring, .100" dia., .250" long
2 Ea. Rolls, Measuring, .200" dia., .250" long
2 Ea. Rolls, Measuring, .300" dia., .250" long
2 Ea. Rolls, Measuring, .100" dia., 1 00" long
2 Ea. Rolls, Measuring, .200" dia., 1 00" long
2 Ea. Rolls, Measuring, .300" dia., 1.00" long
1 Ea. Rule, Flexible steel, 6" number 11 graduations
1 Ea. Rule, Flexible steel, 12" number 11 graduations
1 Ea. Rule, Flexible steel, 18" number 11 graduations
1 Ea. Rule, Flexible steel, 24" number 11 graduations
1 Ea. Rule, Flexible steel, 36" number 11 graduations
1 Ea. Rule, Flexible, narrow tempered steel, 6" number 11 graduations
1 Ea. Rule, Flexible, narrow tempered steel, 12" number 11 graduations
1 Ea. Scriber, double point, 8" long
4 Ea. Screw-drivers, assorted sizes
1 Ea. Square, Cylindrical, 4" dia., 8" long
1 Ea. Square, Universal, 2½" x 3" x ½"
1 Ea. Square, Try, Beveled edge, 3"
1 Ea. Square, Try, Beveled edge, 6"
1 Ea. Square, Try, hardened cast steel, 9"
1 Ea. Square, Try, hardened cast steel, 12"
1 Ea. Square, Try, hardened cast steel, 18"
1 Set Straight Edges, Toolmakers, knife edge, consisting of 6 narrow edges, ½", ¾", 1", 1¼", 1½" and 2" long
1 Set Straight Edges, Toolmakers, knife edge, 2¼", 3¼", 4½", 6¼" long and glass test bar
1 Ea. Straight Edge, beveled steel, 12"
1 Ea. Straight Edge, beveled steel, 18"
1 Ea. Straight Edge, beveled steel, 24"
1 Ea. Straight Edge, beveled steel, 36"
1 Ea. Trammel, steel beam, 20", with 20" extension, caliper points, divider points and V points
1 Ea. Tester, Hardness, Rockwell Superficial, with internal testing attachments
1 Ea. Thread Lead Tester
1 Ea. Vise, Bench, Portable
31 Set Wires, Thread Measuring (3 wires to set), best wires for 4, 4½, 5, 6, 7, 7½, 8, 9, 10, 11, 11½, 12, 13, 14, 15, 18, 20, 22, 24, 27, 28, 30, 32, 36, 40, 44, 48, 56, 64, 72 and 80 pitch
14 Ea. Wires, 29 Degree, Acme Worm Thread Measuring (3 wires to set), best size for 1, 1⅓, 1½, 2, 2½, 3, 4, 5, 6, 8, 10, 12, 14 and 16 pitch
1 Ea. Wrench, Monkey, 6"
1 Ea. Wrench, Monkey, 12"
1 Ea. Hammer, Ball Peen, ¼ lb.
1 Ea. Hammer, Ball Peen, ½ lb.
1 Ea. Tap, .125–40 thread for use with Toolmakers Buttons
1 Ea. Tap, .250–24 thread for use with Toolmakers Buttons

FIG. 10. (*Continued*)

same identification as the instrument, for quickly spotting the absence of, and identifying, any missing instrument. Search for misplaced gages is expensive. All instruments of a similar kind, such as micrometer calipers, vernier calipers, etc., should be grouped together on the same shelf and arranged according to size and graduations. A few containers of silica-jel in instrument cabinets afford protection against moisture.

GAGE RECORD

Name of Gage ....Gage Identification No............
Component on Which Used................................Part Symbol...........
Function of Gage ....
Type of Gage ....
Assembly on Which Used ....
Gage Symbol ....Value.........................
Gage Drawing No............................Revision......................
Component Part Drawing No. ....Revision......................
Assembly Drawing No. ....Revision......................
Date Inspected ....Accepted by..................Date...............

Required Component Dimensions	Actual Gage Dimensions	Location
		Dept. .... Section .... Rack .... Bin .... Tray ....
		Remarks:
Deviations from Gage Drawing..		.... Gage Checker

Rein-spection Date	Inspector	Changes Noted in Dimensions	Recommendation (O.K., Repair, Other Use, Scrap)

Fig. 11. Gage Record Card

When the silica-jel becomes fairly saturated with absorbed moisture it can be dried out in an oven.

Measuring instruments should be coated with moisture- and acid-free greases or oils each time after use, and should be cleaned before use again with white gasoline or benzine.

After gages have been stored, the gage record card should be typed in duplicate, fully describing the use and condition of the gage, one card to be filed numerically and the other under the component on which the gage is used. (See Fig. 11.) Duplication of numbers assigned to gages must be carefully avoided.

History of Each Gage.—Subsequent history of gage reinspections, such as date, by whom, changes in dimensions due to wear, repairs, reissue, or condemnation, should always be added to the gage record card as long as the gage continues in existence. When the gage is destroyed the card should be removed from the active file and transferred to a dead file for future reference, if deemed desirable, or destroyed.

Classification of Inspection Instruments

TWO CLASSES OF INSTRUMENTS.—Measurement instruments may be classified under two general groups:

1. Those graduated to read in fractions of an inch such as 1/2, 1/4, 1/8, 1/16, 1/32, 1/64, and 1/100 of an inch. Such instruments are called **line measurement instruments** and are not to be regarded as precision instruments in any sense.
2. Those instruments capable of measurement to the one-thousandth of an inch or finer, called **precision measurement instruments.** Any measurement coarser than one-thousandth of an inch is not a precision measurement.

On the other hand, precision instruments may be capable of measurements to the millionth part of an inch. The millionth part of an inch may be said to bear the same relation to an inch that the thickness of a new dime does to the height of the Woolworth Building, New York.

PRECISION INSTRUMENTS.—Precision instruments, in turn, may be subdivided according to type and the means employed to obtain their degree of precision.

Dial Gages depend upon a rack-and-pinion movement to augment a very slight movement of the gaging element into a very considerable movement of a pointer over a graduated scale. The two-thousandth of an inch movement of the gaging point may result in a 2-in. movement of the pointer over a scale of that length which, in turn, may be subdivided into easily read graduations representing one ten-thousandth of an inch of movement of the gaging point.

Amplifying Gages are those which employ the principle of the lever and fulcrum such that a ratio of, say, 10-to-1 will produce ten times the movement of the pointer as compared with one-tenth of that movement at the gaging point. Greater amplification is not desirable in a single-lever amplifying instrument because the greater length of the amplifying arm together with its greater weight produces a greater pressure than should be applied by the gaging point against the surface being gaged, giving incorrect results. Where greater accuracy is desired, a compound amplifier is employed such that two 10-to-1 amplifying elements are combined so that the second picks up the movement of the first amplifying pointer and, in turn, amplifies that movement tenfold. By such a device the leverage elements of the instrument are kept down to a practical length, thus eliminating the excess pressure produced by a longer lever arm.

Comparators are those instruments employing the principles of the dial-type or amplifying-type of gages together with an anvil or reference table, such that a definite distance can be provided for between the anvil or table upon which specimens to be gaged are placed, and the gaging point of the instrument which makes contact with the top of the specimen. If a series of roller bearings are to be checked or sorted for size and the basic dimension were .250 in., a precision gage-block .250 in. would be placed between the table and the gaging point and the instrument so set that the pointer would indicate zero reading at the center

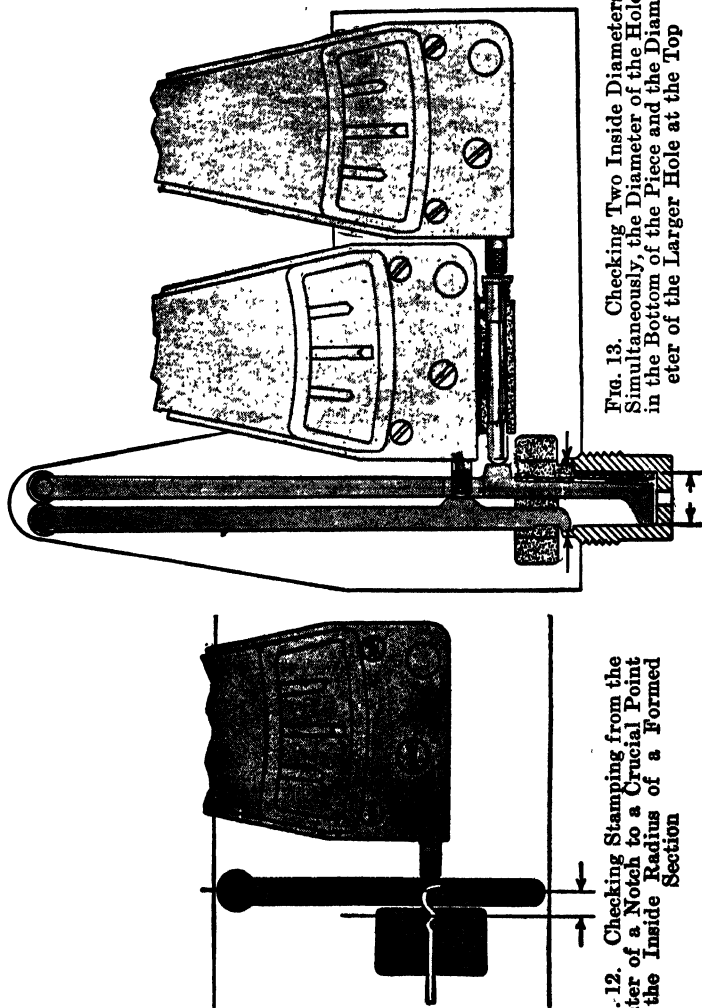



Fig. 12. Checking Stamping from the Center of a Notch to a Crucial Point on the Inside Radius of a Formed Section

Fig. 13. Checking Two Inside Diameters Simultaneously, the Diameter of the Hole in the Bottom of the Piece and the Diameter of the Larger Hole at the Top

of the scale. The gage-block would then be removed and replaced successively by the roller bearings. Those of basic size would cause the pointer to move to the center or zero reading on the scale. Others above or below basic size would be readily sorted by the degree of travel of the pointer, and its distance to the right (plus side) or to the left (minus side) of the center would indicate, in thousandths or ten-thousandths of an inch, the amount the bearings were over or under basic size. Such instruments are in general use in production gaging and sorting work.

A method of comparator gage construction utilizing prefabricated and interchangeable elements for quick setting up on inspection fixtures is shown in the accompanying illustrations (Figs. 12, 13, and 14) of the Micro-Check precision inspection instrument (Trico Products Corp.). The instrument consists essentially of four principal elements—base, adjustable anvil and work holders, gaging members or caliper fingers, and indicating gage with tolerance indicators. The indicating gage and an anvil are placed in position on the base, which is drilled and slotted for adjustability and interchange of anvils and varying positions of the indicator, and the proper work holders and gaging members are set with reference to the anvil and indicator. The gaging members are adjusted to take the reading desired and the tolerance indicators are set, using standard or master parts of known dimensions for the purpose. The instrument is ordinarily operated with the gaging plunger slightly re-

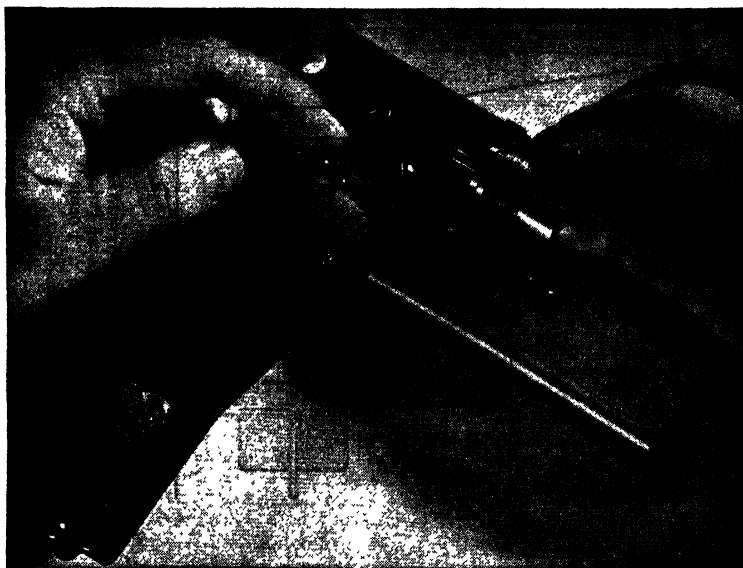



FIG. 14. Braille Type Instrument for Use by Blind Inspectors

tracted. By pressing a button on the indicator, the plunger is released for contact with the piece under inspection. If it is desired to use the instrument as a snap gage, the button control is fastened down by turning a set screw, thus releasing the gaging plunger for immediate contact with the work. For unusual kinds of inspection, anvils and work holders, or fixtures of special kinds can be developed and made by the user. Two such applications are shown in Figs. 12 and 13.

For use by blind inspectors, the Micro-Check instrument has been provided in a Braille type. Limiting fingers extend through the space constituting the dial opening ordinarily used for visual reading, so that readings are taken by finger touch. This device is interchangeable with the visual-type indicator. The instrument may be provided with a hook connection to attach a stirrup for foot operation, leaving both hands free for handling the work.

Optical Instruments are those precision measurement instruments which employ a source of light, such as electric light or concentrated daylight, focused at a given point, in combination with a lens system. One type magnifies either the object under inspection or the shadow of the object—such as the contour of a gear tooth or the thread of a screw —against a screen upon which has been drawn an image of the object as it should appear, but magnified 10, 20, or even 100 diameters. In another type such as a toolmaker's microscope, for example, a screw having 250 threads to the inch can be readily examined and all details measured to an accuracy of one ten-thousandth of an inch as easily as though it were a large screw with only four threads to the inch. A Hartness screw-thread comparator, a Wilder projector, a Jones & Lamson projector (see Fig. 15), and a Bausch & Lomb projector all employ a source of artificial light together with a lens system to project an enlarged and sharp shadow of the contour of the object upon a screen where it may be readily checked against an enlarged drawing, or from which measurements may be directly made by means of the micrometer or angle measuring devices either built into the instruments or available as accessories.

Air Check or Pneumatic Gages employ the principle of air escaping from an orifice obstructed in part by the specimen placed on the instrument. The greater the space between the specimen and the orifice, the greater the escape of air and the consequent deflection of the indicating needle upon the scale graduated in decimals of an inch.

Electrolimit Gages employ electricity such that one or more gaging points make contact with the specimen at the location or locations thereon where gaging is desired. If the specimen is within tolerance at all gaging points a master light so indicates by, say, an amber light. Each individual gaging point also is connected to its particular light on the board which, in this case, also shows amber. If, however, any gaged location on the specimen is not within tolerance, the master light will show red and the individual light for this point will show red for plus and green for minus. Thus specimens can be quickly gaged at numerous positions simultaneously while merely observing the master light for acceptance or rejection signals.

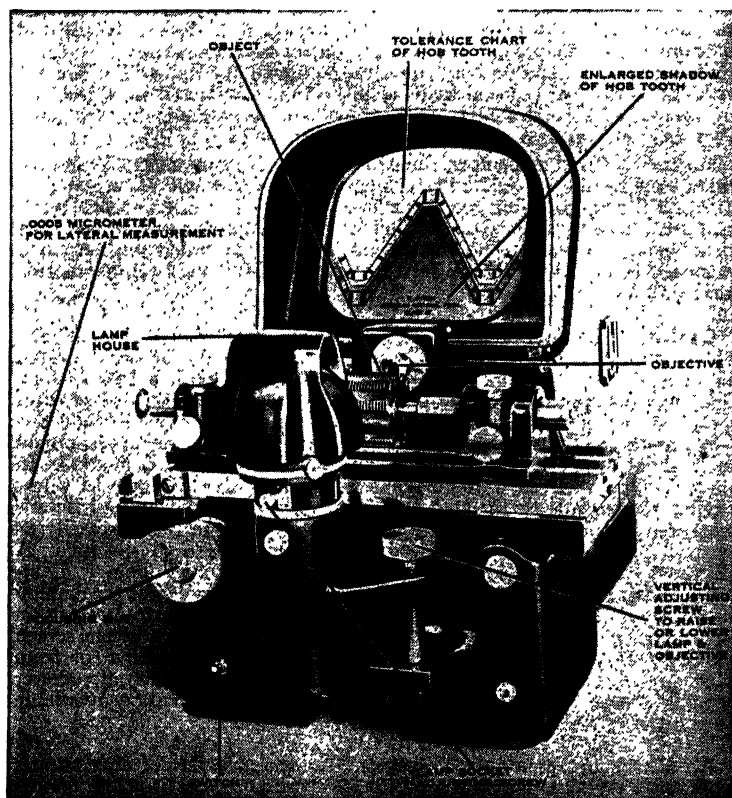



FIG. 15. Standard Optical Bench Comparator Inspecting a Hob

Receiver Gages are those gages built so as to receive, by insertion, an irregularly shaped object, such as a cam, which can be inserted only if its contour conforms to that part of the gage recessed to receive it.

Functional Gages, as the name implies, check the performance of the object, usually an assembly of component parts—each of which was individually inspected during manufacture—to assure the proper functioning of the assembled object. The breech end of a gun may be such a functional gage into which successive rounds of assembled fixed ammunition are inserted to determine if the breech block will then close and lock properly.

GAGE CLASSIFICATION ON THE BASIS OF ACCURACY.—There are three general commercial gage classifications. These are exemplified in grading precision gage-blocks as follows:

Grade AA	Guaranteed accuracy = .000002 in.
Grade A	Guaranteed accuracy = .000004 in.
Grade B	Guaranteed accuracy = .000008 in.

Grade AA would be limited to laboratory use where great exactitude of measurement is essential, such as reference measurements for gage setting.

Grade A would be used for layout work, or for setting other instruments, or for checking working or shop gages.

Grade B could be used directly on parts inspection, or used the same as Grade A.

Another classification for gages is master or reference, inspection, and working, in the order of their accuracy. **Master gages** are those gages especially designed to check a particular gage as, for instance, a profile gage would be checked by a master gage whose profile would be the opposite of the gage to be checked, so that it could be mated or meshed with the profile gage to determine any points at which the two profiles did not contact.

Formerly plain gages, such as **plain plug gages**, were checked by a master gage which was the opposite to the plug, i.e., a hole or a ring gage. The great expense involved in making master gages has been practically eliminated, except for contours and profiles, by the use of precision gage-blocks in conjunction with the accessories that come with them, rendering them applicable to a wide variety of gage checking.

Methods of Gaging

Various new types of gaging devices and methods have been developed in the past decade, many having been reported in technical literature.

DIAL INDICATOR GAGING.—Dial indicators are found in a wide field of application (Amer. Mach., vol. 84). A method of determining the size of a round shaft is that of determining altitude h of an inscribed triangle (see Fig. 16) where $h = r + \sqrt{r^2 - a^2}$. Differentiating h with respect to r,

$$\frac{dh}{dr} = 1 + \frac{r}{\sqrt{r^2 - a^2}}$$

As can be seen, the indicator will not directly show variations in diameter. By proper graduation, however, the dial of the indicator can be made to show variations in diameter directly.

For most purposes **precision gage-blocks** of the Johansson or Hoke types are suitable as masters (Amer. Mach., vol. 84). Plug and ring gages are regarded in many cases as untrustworthy and are being replaced by other devices.

AUTOMATIC MACHINE GAGING DEVICES.—Automatic gages may be classified as implements with one, two, three, or more

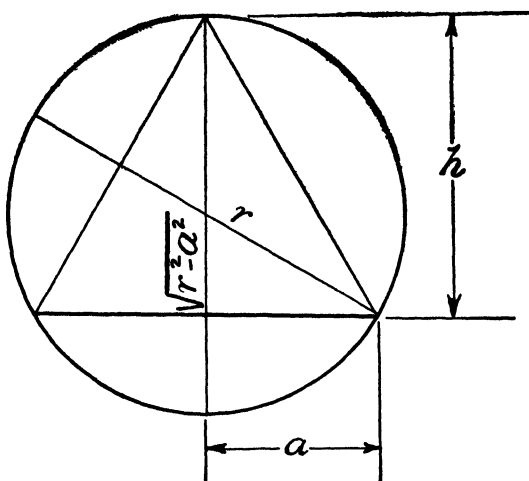



FIG. 16. Diagram Showing Method of Calculating Size of Round Shaft from Dial Indicator Reading

point contact. Only with measuring devices of three-point principle can measurement be made during operation without difficulties of vibration. Also, there are roughing and finishing gages which automatically will test the size of holes at frequent intervals (Engineering, vol. 139).

A recent development in automatic measuring consists in utilizing compressed air, with or without electrical connections, employing the principle that escaping air from a pressure line will affect line pressure if size and shape of outlet be varied (Engineering, vol. 139). Another instrument is an electric sizing device which compresses a gage resting on the work until the size is obtained, when electric contact is made stopping the wheel feed and lifting the gage from the work.

ELECTRONIC INSPECTION.—Electronic inspection, often used for go and not-go gaging, is accurate to .00008 in. when handling pieces at uniform temperature, and materially speeds up manual inspection operations (Amer. Mach., vol. 78). It is also used for automatic weighing.

The so-called "pinhole detector" is a typical example of an electronic inspection instrument. Until recently, the problem of detecting pinholes 1/64 in. in diameter, and smaller, in strips of sheet steel traveling at speeds of 1,000 ft. per min. would have been considered impractical, if not almost impossible. Now, however, a photo-electric control device—the pinhole detector—not only does this work accurately but also marks the defective portion of the strip or initiates a "memory device" which later rejects the particular sheet in which a hole is present.

Steel used for cans must be free from any imperfections which would permit leaks. Formerly, for inspection, the tin stock was brought to the

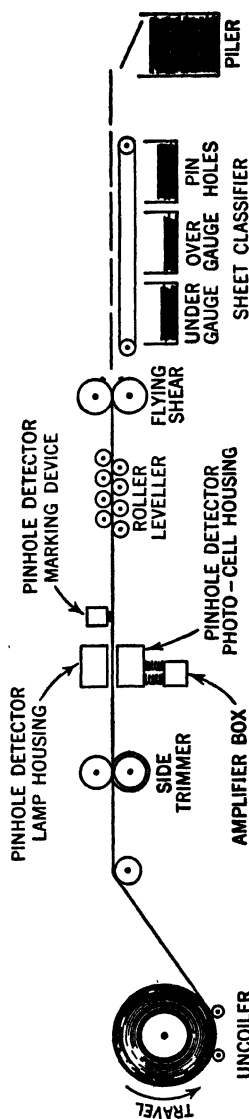



FIG. 17. Diagram of Electronically Controlled Inspection of Metal Strip (Westinghouse Electric & Mfg. Co.)

shearing line of the rolling mill and cut into sheets from 6 to 12 ft. in length. These sheets then proceeded along a conveyor into a dark room. Here extremely brilliant lights were directed against the sheets from the lower side and workmen inspected the sheets for small holes as they moved along the conveyor line. This was a tiring task on the eyes and it was necessary to have several inspectors working alternately in shifts of two or three hours. The maximum speed of inspection was approximately 50 ft. per min.

The photo-electric pinhole detector has changed this process considerably. Instead of inspecting the steel after it is cut up in sheets, the pinhole detector scans it while still in strip form. Fig. 17 shows diagrammatically the layout of the equipment. A light source which throws a narrow but powerful band of light completely across the strip is placed above the strip, and a phototube housing is placed underneath it directly under the light source. When a hole is present in the sheet, light passes through and falls on one of the phototubes. The electrical impulse thus created is amplified and applied to the grids of a thyratron tube which "fires" and operates a relay. This, in turn, may operate a warning signal, stop the mill, or initiate a marking device, which marks the portion of the strip containing the pinhole. Later the strip is cut into sheets and those that are marked can easily be ejected by workmen.

Occasionally, as stated above, the pinhole detector is used to initiate a "memory device." This has the unique ability of "remembering" what section of the strip was defective, and when the sheet containing this defect is carried along the conveyor line to a predetermined point the memory device operates a solenoid which ejects it.

The pinhole detector is capable of detecting holes as small as 1/64 in. in diameter at strip speeds of from 100 to 1,000 ft. per min. This equipment in many cases has speeded up the inspection of tin stock. In addition, it has also saved the manufacturer large sums of money because of the former rejection of the defective material by the ultimate consumer.

OTHER METHODS OF GAGING.—The Warner & Swasey standard of length is embodied in a 4-ft. Pratt & Whitney measuring machine, accurate to within .00001 in., kept in a constant temperature room (Iron Age, vol. 145). Shop gages are checked against the standard by means of precision gage-blocks and comparators. The latest type Pratt & Whitney **electrolimit gage** combines mechanical gaging with electrical magnification and is graduated into twenty-millionths of an inch. The use of master discs or comparators on work eliminates the human element, since the operator instinctively "mikes" both work and standard with the same touch. **Bar gages** are also used extensively in the Warner & Swasey shops.

The Bausch & Lomb **contour measuring** projector throws a magnified image of the work onto an 18-in. ground-glass screen (Iron Age, vol. 129). With magnification to 100 times, it is useful in checking screw threads, plug gages, thread ring gages, cams, etc. **Light waves** are used as primary standards in conjunction with optical flats (Iron Age, vol. 136).

Surface quality has been taken out of the "look-feel" category by an **electrically operated profilometer** which explores the surface with a needlepoint whose findings are telegraphed to a dial graduated in mil-

lionths of an inch (Steel, vol. 105). Another important matter in connection with gaging is balance. A **stroboglow balancing machine** makes use of the apparent stoppage of rapid motion with stroboscopic effect.

The greatest advances made during the last ten years in the field of gaging have centered around the use of electrical and pneumatic devices and the well-known physical properties of light which makes feasible the use of light as a primary standard. Specifications of industry are becoming more exacting and the day of the micrometer and caliper is fast fading. The keynote now is for "accurate" mass production of interchangeable parts in which advanced gaging methods play an important part.

Glass Precision Gages

ADVENT OF GLASS GAGES.—As is frequently the case, the urgency for certain materials during times of national emergency may be so great as to make necessary the substitution of other materials more readily available and serving the purpose equally well, if not better. Prior to the end of 1941, the total gage manufacturing capacity of the United States was estimated at between three million and four million dollars annually. With the advent of the Second World War it was apparent that the existing gaging facilities would be unable to cope with the demands that would be made upon them, because of the war-

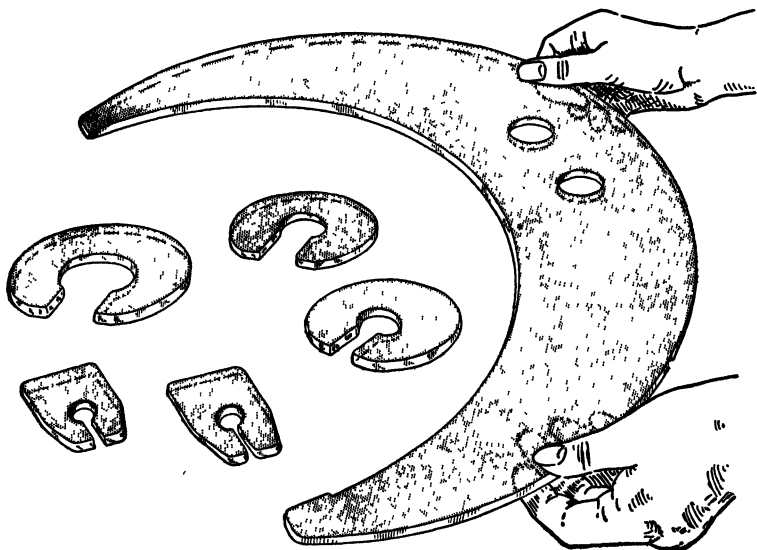



FIG. 18. Typical Glass Gages

Corning Glass Works
GLASS RING GAGE BLANKS
Data Sheet No. 833

CODE NO.	A RANGE		GENERAL DIMENSIONS		
	ABOVE	TO AND INCLUDING	B	C	D
77050	.365"	.510"	1 3/8"	7/8"	1 1/4"
77051	.510"	.675"	1 3/8"	7/8"	1 1/4"
77052	.675"	.825"	1 3/4"	1 1/16"	1 5/8"
77053	.825"	.975"	1 3/4"	1 1/16"	1 5/8"
77054	.975"	1.135"	2 1/2"	1 1/4"	2 3/8"

FIG. 19. Data Sheet for Glass Ring Gage Blanks

Corning Glass Works
GLASS PLUG GAGE BLANKS
Data Sheet No. 834

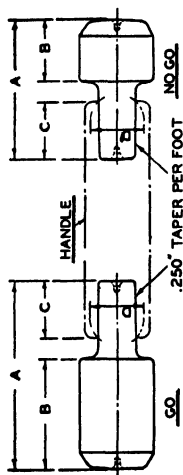
A B C HANDLE D GO .250" TAPER PER FOOT NO GO

CODE NO.	HANDLE SIZE NO.	RANGE IN DIAMETER		GENERAL DIMENSIONS GO					CODE NO.	GENERAL DIMENSIONS NO GO				
		ABOVE	TO AND INCLUDING	A	B	C	D MIN.	D MAX.		A	B	C	D MIN.	D MAX.
77102	2	.365"	.510"	2 1/4"	1 1/4"	3/4"	.309"	.310"	77150	1 5/8"	5/8"	3/4"	.309"	.310"
77103	3	.510"	.675"	2 1/2"	1 1/2"	3/4"	.408"	.410"	77151	1 3/4"	3/4"	3/4"	.408"	.410"
77104	3	.675"	.825"	2 1/2"	1 1/2"	3/4"	.408"	.410"	77152	1 3/4"	3/4"	3/4"	.408"	.410"
77105	4	.825"	.975"	2 7/8"	1 11/16"	7/8"	.608"	.610"	77153	2 1/8"	15/16"	7/8"	.608"	.610"
77106	4	.975"	1.135"	2 7/8"	1 11/16"	7/8"	.608"	.610"	77154	2 1/8"	15/16"	7/8"	.608"	.610"

FIG. 20. Data Sheet for Glass Plug Gage Blanks

fare that would be carried on to an extent exceeding anything in history. Accordingly, the United States spent approximately twenty million dollars in increasing the gage facilities of existing gage makers or in creating new facilities such that the total annual capacity of the country for precision gages was increased to one hundred and twenty-five million dollars.

The mere increase in gage manufacturing facilities, however, did not provide for the corresponding increase in the special steel requirements involved, which steels were also vitally needed in other war efforts. Consequently gage material other than steel was sought by the Ordnance Department of the United States Army. Because of the hard and smooth surface of glass and the plentiful supply of glassmaking ingredients, as well as the existence of several glass industries, the idea of glass gages was given serious consideration and steps were initiated at Frankfort Arsenal toward experimenting with this material. As a result, some satisfactory gages have been produced and used for a sufficiently long period to justify glass as a very definite and permanent gage material. Fig. 18 shows illustrations of glass plug and glass ring gages, and Figs. 19 and 20 are data sheets covering such gages.

Advantages of Glass Gages.—Many problems yet remain to be solved in the light of subsequent experience but there can be definitely credited to glass the following advantages:

1. The very fact that a gage is made of glass prompts the user to greater care in its handling and application on inspection work.
2. A steel gage may be sprung or deformed if dropped, impairing thereby its gaging functions, whereas a glass gage will either break or remain unchanged dimensionally.
3. When the part which is being inspected is very close to the size of the gage, there is a tendency to "seize" in a steel gage, whereas there is far less tendency for this to occur with a glass gage.
4. When using a glass gage the sense of "feel" is much more pronounced.
5. Steel gages are subject to corrosion, whereas glass gages are not.
6. Greasing and degreasing, so necessary with steel gages, is entirely dispensed with for glass gages, which do not corrode or rust.
7. Visibility during inspection is afforded by glass gages.
8. The time required for annealing, machining, and heat-treating is saved, and the distortion attending the manufacture of steel gages is eliminated.
9. The body heat of inspectors is not transmitted so rapidly to the gage as to affect gaging dimensions because of the lesser thermoconductivity of glass.
10. Neither slight chipping nor scratches on glass gages have any effect upon their gaging functions, nor do they burr the glass.
11. The abrasive-resisting qualities of glass gages appear to be superior to those of steel gages.
12. The production of glass gages in the quantities required for wartime purposes released the corresponding requirements for tool steel.

Accuracy of the Gages.—Apart from the technique of glass-gage making, which has been rapidly developed, it is interesting to note that the accuracy life of glass gages has been demonstrated, in certain applications, to be far in excess of that of similar steel gages. For example, one glass plug gage was used for checking the opening of brass cartridge cases and after 260,000 applications was still found within its accuracy

life. A corresponding steel gage accuracy life is between 50,000 and 60,000 applications.

Composition and Properties.—Gages so far have been produced from commercial glass of light flint and boro-silicate grades, colorless in appearance, and from plate or molded stock. Owing to the difference in the modulus of elasticity—30,000,000 lb. per sq. in. for steel and 10,000,000 lb. per sq. in. for glass—there is a natural difficulty in processing glass gages owing to the three times greater flexure of glass under load—an important consideration in chucking for grinding and lapping operations. Glass also has a different coefficient of expansion as compared with steel, ranging from .0000018 in. per degree F. for boro-silicate glass to .0000050 in. for crown and plate glass, as compared with .0000060 in. on the average for gage steel. Further researches are being conducted with a view to producing a composition of glass with a coefficient closer to that of steel. Glass gages weigh approximately one-third as much as steel gages, an important consideration in the repetitive use of larger-size gages.

Standards for glass-gage designs differ in some respects from those for steel gages due to certain technicalities in the manufacture and purpose of the material. However, although at first plug gages less than ⅜ in. in diameter were not feasible, and most of the gages produced have been of the plain plug, plain ring, or limit-gage type, it is expected that profile thread plug and thread ring and flush pin gages and many other types eventually will be available.

The cost of glass gages compares most favorably with the cost of steel gages and the time required for production is a fraction of the time required for steel gages.

Army Ordnance Gaging System

NECESSITY FOR HIGH ACCURACY.—The advent of mass production and improvements in machine tools have made possible the stipulation of finer tolerances to produce work more closely to basic dimensions. Commercial practice, however, is not sufficiently refined in accuracy to meet many requirements in the production of ordnance material. The Ordnance Department of the U. S. Army, therefore, has developed a system of gaging war material produced under its jurisdiction. The drawings for both the material desired, and for the inspection gages with which it will be checked, are prepared by the Ordnance Department. Its gage-control system includes a card-index system on which are recorded all data pertinent to a gage throughout its accuracy life. Periodic reference to these files by the gage-control laboratory makes possible the replacement of a gage approaching the end of its accuracy life before that condition has been reached and defective work has been passed because of it. Carboloy gages are coming into use because of their durability.

TOLERANCES FOR U. S. ARMY ORDNANCE DEPARTMENT GAGES.—The Ordnance system of gage design is based on a recognition of the inability or impracticability of a gage-maker adhering

PLAIN GAGES									
PLAIN RING, PLUG, AND SNAP GAGES					ADJUSTABLE SNAP FLUSH PIN AND LENGTH				
COMPONENT	GO GAGE		NOT-GO GAGE		COMPONENT	MAXIMUM GAGE		MINIMUM GAGE	
TOTAL TOLERANCE	ALLOWANCE	TOLERANCE	ALLOWANCE	TOLERANCE	TOTAL TOLERANCE	ALLOWANCE	TOLERANCE	ALLOWANCE	TOLERANCE
.0005	.0001	.00005	.00005	.00005	.0005	.0001	.0000	.0000	.0000
.001	.0002	.0001	.0001	.00005	.001	.0001	.0001	.0000	.0001
.002	.0003	.0001	.0001	.0001	.002	.0002	.0001	.0001	.0001
.003	.0004	.0002	.0001	.0001	.003	.0002	.0002	.0001	.0001
.004	.0006	.0002	.0002	.0001	.004	.0003	.0002	.0002	.0001
.005	.0007	.0002	.0002	.0002	.006	.0004	.0002	.0003	.0002
.006	.0008	.0002	.0002	.0002	.010	.0005	.0002	.0005	.0002
.007	.0009	.0002	.0002	.0002	.015	.0006	.0003	.0006	.0003
.008	.0010	.0002	.0002	.0002	.020	.0007	.0004	.0007	.0004
.009	.0011	.0003	.0002	.0002	.025	.0007	.0005	.0007	.0005
.010	.0012	.0004	.0003	.0002	.030	.0007	.0006	.0007	.0006
.012	.0015	.0005	.0003	.0003	.040	.0007	.0008	.0007	.0008
.014	.0017	.0006	.0004	.0003	.050	.0007	.0010	.0007	.0010
.015	.0018	.0007	.0005	.0004	.065	.0008	.0010	.0007	.0012
.016	.0020	.0008	.0005	.0004	.100	.0010	.0015	.0010	.0015
.018	.0020	.0009	.0006	.0005					
.020	.0020	.0010	.0007	.0006					
.022	.0020	.0010	.0008	.0007					
.024	.0020	.0010	.0009	.0008					
.025	.0020	.0010	.0010	.0010					
.030	.0021	.0010	.0010	.0010					
.040	.0022	.0010	.0010	.0010					
.050	.0023	.0010	.0010	.0010					
.065	.0025	.0010	.0010	.0010					
.100	.0030	.0010	.0010	.0010					

FIG. 21. Table of U. S. Army Ordnance Department Recommended Allowances and Gage-Maker's Tolerances for Working Gages

PLAIN GAGES						
PLAIN RING, PLUG, AND SNAP GAGES				ADJUSTAELE SNAP, FLUSH PIN, AND LENGTH		
COMPONENT	GAGE			COMPONENT	GAGE	
		TOLERANCE			TOLERANCE	
TOTAL TOLERANCE	WEAR ALLOWANCE	GO	NOT-GO	TOTAL TOLERANCE	GO	NOT-GO
.0005	.0000	.0001	.00005			
.001	.0001	.0001	.00005	.001	.0001	.0001
.002	.0001	.0001	.0001	.002	.0001	.0001
.003	.0001	.0002	.0001	.003	.0001	.0001
.004	.0002	.0002	.0002	.004	.0002	.0002
.005	.0003	.0002	.0002	.010	.0003	.0003
.006	.0004	.0002	.0002	.015	.0004	.0004
.007	.0004	.0003	.0002	.020&UP	.0005	.0005
.008	.0005	.0003	.0002			
.009	.0005	.0004	.0002			
.010	.0005	.0005	0003			
.012	.0006	.0006	.0003			
.014	.0006	.0008	.0004			
015	.0006	.0009	0005			
.016	.0006	.0010	.0005			
018	.0006	.0010	.0006			
.020	.0006	.0010	.0007			
.022	.0006	.0010	.0008			
.024	.0006	.0010	.0009			
.025&UP	.0006	.0010	.0010			

FIG. 22. Table of U. S. Army Ordnance Department Recommended Allowances and Gage-Maker's Tolerances for Inspection Gages

to basic dimensions any more than can the machinist adhere to the basic dimensions stipulated for component parts. He must have some leeway or tolerance within which to produce acceptable work. In addition to providing a "workman's tolerance," provision must also be made for wear as the gage is used. Since working gages are in more constant use than inspection gages, they will suffer more wear over a given period than will inspection gages. Therefore, so that the **inspection gage** will not reject work which has been accepted by a worn working gage still within its accuracy life, in the design of the inspection gage the required gage-maker's tolerance is so provided as to be within the tolerance prescribed on the drawing of the component part in question. To that is added a wear allowance for that gage such that the combined gage-maker's tolerances are within the component tolerance.

In the design of the **working gage**, both a gage-maker's tolerance and a wear allowance are provided so that they are within the limits pre-

PLUG AND RING THREAD GAGES 1 AND 2 FIT

Threads per inch	Go gage pitch diameter: Allowance	Go gage pitch diameter: Tolerance	Not-go gage pitch diameter: Allowance	Not-go gage pitch diameter: Tolerance	Tolerance in lead ±	Tolerance on ½ angle: Go	Tolerance on ½ angle: Not-go	Major diameter or minor diameter, Go gage: Allowance	Major diameter or minor diameter, Go gage: Tolerance	Major diameter or minor diameter, Not-go gage: Allowance	Major diameter or minor diameter, Not-go gage: Tolerance
80	.0003	.0002	.0002	.0002	.0002	45'	30'	.0003	.0003	.0003	.0003
72	.0003	.0002	.0002	.0002	.0002	45'	30'	.0003	.0003	.0003	.0003
64	.0004	.0003	.0002	.0002	.0002	45'	30'	.0004	.0004	.0003	.0003
56	.0004	.0003	.0002	.0002	.0002	45'	30'	.0004	.0004	.0004	.0004
48	.0004	.0003	.0002	.0002	.0002	45'	30'	.0004	.0004	.0004	.0004
44	.0004	.0003	.0002	.0002	.0002	30'	20'	.0004	.0004	.0004	.0004
40	.0004	.0003	.0002	.0002	.0002	30'	20'	.0004	.0004	.0004	.0004
36	.0005	.0003	.0002	.0002	.0002	30'	20'	.0004	.0004	.0004	.0004
32	.0005	.0003	.0003	.0003	.0002	20'	15'	.0004	.0004	.0004	.0004
28	.0006	.0003	.0003	.0003	.0002	20'	15'	.0005	.0005	.0005	.0005
24	.0007	.0003	.0003	.0003	.0002	20'	15'	.0005	.0005	.0005	.0005
20	.0007	.0003	.0003	.0003	.0002	20'	15'	.0005	.0005	.0005	.0005
18	.0007	.0003	.0003	.0003	.0002	15'	10'	.0005	.0005	.0005	.0005
16	.0008	.0004	.0003	.0003	.0003	15'	10'	.0006	.0006	.0006	.0006
14	.0008	.0004	.0003	.0003	.0003	15'	10'	.0006	.0006	.0006	.0006
13	.0008	.0004	.0003	.0003	.0003	15'	10'	.0006	.0006	.0006	.0006
12	.0008	.0004	.0003	.0003	.0003	10'	10'	.0006	.0006	.0006	.0006
11	.0008	.0004	.0003	.0003	.0003	10'	10'	.0006	.0006	.0006	.0006
10	.0008	.0004	.0003	.0003	.0003	10'	10'	.0006	.0006	.0006	.0006
9	.0009	.0005	.0003	.0003	.0003	10'	5'	.0007	.0007	.0007	.0007
8	.0009	.0005	.0004	.0003	.0003	5'	5'	.0007	.0007	.0007	.0007
7	.0009	.0005	.0004	.0003	.0003	5'	5'	.0007	.0007	.0007	.0007
6	.0010	.0005	.0004	.0004	.0003	5'	5'	.0008	.0008	.0008	.0008
5	.0010	.0005	.0004	.0004	.0003	5'	5'	.0008	.0008	.0008	.0008
4½	.0011	.0005	.0004	.0004	.0003	5'	5'	.0008	.0008	.0008	.0008
4	.0012	.0006	.0004	.0004	.0003	5'	5'	.0009	.0009	.0009	.0009

FIG. 23. Table of U. S. Army Ordnance Department Recommended Allowances and Gage-Maker's Tolerances for Working Gages

PLUG AND RING THREAD GAGES

Class 1 and 2 Fit

Threads per inch	Go gage: Wear allowance	Go gage: Gage makers tolerance	Not-go gage: Gage makers tolerance	Tolerance in lead	Tolerance on ½ angle: Go	Tolerance on ½ angle: Not-go	Tolerance on major dia. thd. plug & minor dia. thd. rings
80	.0001	.0002	.0002	.0002	45'	30'	.0003
72	.0001	.0002	.0002	.0002	45'	30'	.0003
64	.0001	.0003	.0002	0002	45'	30'	.0004
56	.0001	.0003	.0002	0002	45'	30'	.0004
48	.0001	.0003	.0002	.0002	45'	30'	0004
44	.0001	.0003	.0002	.0002	30'	20'	0004
40	.0001	.0003	.0002	.0002	30'	20'	.0004
36	.0001	.0003	.0002	.0002	30'	20'	.0004
32	.0001	.0003	.0003	.0003	20'	15'	.0004
28	.0002	0003	.0003	.0003	20'	15	.0005
24	.0002	.0003	.0003	.0003	20'	15'	.0005
20	0002	.0003	.0003	.0003	20'	15'	.0005
18	.0002	.0003	.0003	.0003	15'	10'	.0005
16	.0002	.0004	.0003	.0003	15'	10'	.0006
14	.0002	.0004	.0003	.0003	15'	10'	.0006
13	.0002	.0004	.0003	.0003	15'	10'	.0006
12	.0002	.0004	.0003	.0003	10	10'	.0006
11	.0002	.0004	.0003	.0003	10'	10'	.0006
10	.0002	.0004	.0003	.0003	10'	10'	.0006
9	.0002	.0005	0003	.0003	10'	10'	.0007
8	.0002	.0005	.0004	.0004	5'	5'	.0007
7	.0002	.0005	.0004	0004	5'	5'	.0007
6	.0003	.0005	0004	.0004	5'	5'	0008
5	.0003	.0005	.0004	.0004	5'	5'	.0008
4½	.0003	.0005	.0004	0004	5'	5'	0008
4	.0003	0006	.0004	.0004	5'	5	.0009

Class 3 Fit

Threads per inch	Go & not-go gage: Gage makers tolerance	Tolerance on ½ angle: Go	Tolerance on ½ angle: Not-go	Tolerance on major dia. thd. plug & minor dia. thd. rings
80	.0001	30'	30'	.0003
72	.0001	30'	30'	.0003
64	.0001	30'	30'	.0004
56	.0001	30'	30'	.0004
48	.0001	30'	30'	.0004
44	.0001	20'	20'	.0004
40	.0002	20'	20'	.0004
36	.0002	20'	20'	.0004
32	.0002	15'	15'	.0004
28	.0003	15'	15'	.0005
24	.0003	15'	15'	.0005
20	.0003	15'	15'	.0005
18	.0003	10'	10'	.0005
16	.0003	10'	10'	.0006
14	.0003	10'	10'	.0006
13	.0003	10'	10'	.0006
12	.0003	10'	10'	.0006
11	.0003	10'	10'	.0006
10	.0003	10'	10'	.0006
9	.0003	10'	10'	.0007
8	.0004	5'	5'	.0007
7	.0004	5'	5'	.0007
6	.0004	5'	5'	.0008
5	.0004	5'	5'	.0008
4½	.0004	5'	5'	.0008
4	.0004	5'	5'	.0009

Class 4 Fit

Threads per inch	Go and not-go gage: Gage makers tolerance	Tolerance on ½ angle: Go	Tolerance on ½ angle: Not-go	Tolerance on major dia. thd. plug & minor dia. thd. rings
80				
72				
64				
56				
48				
44				
40				
36				
32				
28				
24				
20				
18				
16				
14				
13				
12				
11				
10				
9				
8				
7				
6				
5				
4½				
4				

FIG. 24. Table of U. S. Army Ordnance Department Recommended Allowances and Gage-Maker's Tolerances for Inspection Gages

scribed for the inspection gage as well as for the component, thus providing for considerable use of the gage before it reaches its accuracy life when it would pass work that the inspection gage would reject.

Figs. 21 to 24 give recommended allowances and gage-maker's tolerances for various working and inspection gages as indicated. (See also Nealy, Iron Age, vol. 84.)

The direction in which the tolerances should be taken is indicated in the following note:

Plug gages:	Go	+ tolerance − zero
	Not-go	− zero + tolerance
Thread gages:	Go	+ tolerance − zero
	Not-go	− zero + tolerance
Ring gages and snap gages:	Go	− tolerance + zero
	Not-go	+ tolerance − zero

SECTION 10

QUALITY CONTROL

CONTENTS

Acceptance Sampling Inspection Plans

SECTION 10

QUALITY CONTROL

NECESSITY FOR QUALITY CONTROL.—The necessity for providing a control of quality in economical manufacturing of goods suited to commercial needs springs from the clash of two facts of production. This is pointed out by George S. Radford as follows:

1. It is general experience that economy of production, distribution, and consumption are greatest when the products of industry are of definite and uniform quality; that is, of standardized quality.
2. It is a physical truth that no two articles are alike; that is, quality varies continually. Raw materials, coming from nature as all do primarily, are of varying quality; no matter what manufacturing processes are applied to them subsequently, the quality of the resulting product varies more or less, depending upon the degree of technical refinement attained. Thus, quality in fact is always tending to slip away from the desired or ideal standard.

Uniformity, the desideratum, is opposed by the fact that quality is a variable. The situation is met in a practical way by striking a compromise between the two, and thus limits are established to define the variations from the ideal standard which may be permitted or tolerated in the commercial product without sacrificing the principle of standardization.

From this situation it follows that control of quality in manufacturing is that function which insures that product is held to definite and uniform quality standards within specified limits, preferably at all stages of manufacture. Its principal instrument is inspection, which judges and measures the quality actually produced, and thus provides facts for the management's use in keeping quality of the product under control within reasonable manufacturing and commercial requirements.

Radford has also emphasized the tendency to a general upward trend in quality standards in manufacturing; the fallacy of assuming that quality is of necessity synonymous with high costs; and the fact that the reverse is true. When quality is controlled, quantity takes care of itself—output of salable goods increases, costs of production and selling decrease; and quality establishes the market which makes possible quantity production with its attendant advantages.

DEFINITION.—Competition and technological requirements have demanded ever greater knowledge and control of the factors related to variations in product characteristics. Such control has become of necessity a science of first magnitude, stressing systematic supervision and refinement of process variables.

The term "quality control" has been used widely and loosely. In some cases it represents conventional acceptance screening inspection, perhaps

including records whereby defects can be assessed sooner or later with particular inspectors, departments, heats, etc. In other cases the term applies to complaint investigations and explanations. Still further, some consider the superficial forms of patrol inspection in this category, but rarely making efficient use of the control information available. Quality control is used by professional managements today in a dynamic sense. It is directed at the prevention of defects and unnecessary variability in process factors, rather than primarily at acceptance inspection of parts and products after defects occur. The act of such inspection, though efficient, is not control. The information obtained can be valuable for general supervision, but as long as assignable or removable causes of variability are present, supervision of contributory process variables is necessary. Statistical techniques play a large part in these scientific methods of systematic observation, reliable interpretation, and prompt corrective action. **Without action** both control and quality fall away, and both methods and quality organization deteriorate to become sterile overhead expense.

Much industrial knowledge of generally recognized process factors has been amassed by trial and error experience or by laboratory experiments. Though both are forms of research, it is difficult to establish reliably the long-run influence of particular variables or to project all interactions that appear in actual manufacturing. Statistical research based upon the records of process variables can profitably supplement and direct basic research. Here more advanced applications of mathematical statistics may be necessary.

But usually the attainment of control is by far the greater need in industry. Simple statistical techniques here are sufficient to implement the systematic approach to supervision, providing say 90% of the possible benefits.

A question frequently asked is, "What size of plant is necessary to use these methods?" The **methods are fundamental,** and can be used profitably on a single machine or process. Size of plant influences only the pattern of organization for the functional direction of control methods and direct responsibility for coordination. In a small plant, a process or production engineer can cover the work. In a large plant, a separate quality control department can more economically specialize subfunctions and coordinate quality responsibility.

MARKET QUALITY.—The efficiency of competitive manufacturing enterprise is measured broadly through accumulated differences between price and cost, the latter as functions of a third variable, quality. An essence of quality is customer utility. Specifically, a manufacturer projects a quality standard corresponding to a competitive level of utility, and a customer purchases against the proffered standard, subject to later verification. Obviously, market price and sales volume are functions of the quality standard offered and **the buyer's degree of confidence** that the product will conform to standard.

A product standard is usually described in terms of physical and chemical characteristics, with that degree of completeness and circumscription necessary to distinguish one degree of competitive utility from another. Since some variability in each characteristic is technically and economically unavoidable in manufacturing, a standard is specified largely in terms of limits of acceptable variation in characteristics.

To **justify buyer confidence,** a manufacturer must observe one or both of two operations: (1) fully and reliably inspect all units of parts and products, to screen out nonconforming units before they reach his market; (2) control the variability of quality characteristics at source to a degree where few, if any, parts and products fail to meet their respective standards.

PRODUCTION CONTROL OF QUALITY.—Complete and reliable **screening inspection** of all parts and products is costly; in cases of destructive inspection it is impossible. Assuming complete screening, shipping only acceptable quality, poor control of the variability of characteristics manufactured must result in high scrap losses along the production line, interruptions and loss of capacity, costly salvage operations, and often selective assembly.

The costs of poor control and elaborate screening may well reduce, if not jeopardize, the competitive position of a manufacturer. If inspection is slighted at the expense of quality shipped to market, the manufacturer's position with regard to market value and volume is endangered.

There has been some confusion of the functions of acceptance inspection and quality control, and a careless use of the latter designation for groups concerned essentially with the administration of commercial complaints. Certain principles are recognized. The act of screening inspection, though perfectly performed, cannot "inspect" quality into a product; it merely shunts out the nonacceptable units **after manufacture.** Quality control involves analysis and progressive refinement of production processes, identifying and acting upon detectable causes of variability and defects—**before poor quality** can be made. Good control is impossible without good control of the factors of production, the four "M's": materials, men, machines, and measurements. Analytical control is a powerful and profitable service which should operate independently to coordinate the three major divisions of production: engineering, operations, and inspection.

In some cases removable causes of variability and defects are identifiable through a direct approach from properly prepared inspection data. In many other cases, with complex and obscure causes underlying variations and defects, the techniques of mathematical statistics provide the means to control.

STATISTICAL METHODS IN CONTROL.—The value of the statistical approach cannot be overstressed. It is recognized in the technical and administrative training of key men of progressive organizations. If balanced methods are used as a guide to action, conditioned with sound engineering judgment, and with due regard for costs and values, they become one of the most valuable assets of modern productive enterprise.

Much has been written in recent years of the purely statistical aspects of control. They are basic in any competent understanding of control. But the methods are tools, like trigonometry and chemical analysis, to be adapted to the background of each problem. With a product of simple design, exacting specifications, and relatively high unit value, illustrated by the ball-bearing, the reclamation afforded by more advanced methods may warrant an expenditure of as much as a third of manufacturing labor-hours in purely statistical control methods. With

a product of relatively low precision requirements, assembled from semifinished components of relatively low unit value, illustrated by a lamp base, the simpler and more direct approaches of routine patrol and screening inspection may suffice, with perhaps only a small outlay of control effort warranted. The essential benefits of the modern analytical approach to quality control derive from an emphasis upon economic and systematic ways of thinking about cause and effect, through observation, interpretation, and action.

A specific example is given by Andrew B. Holmstrom, Vice-President and General Manager, Abrasive Division, Norton Company, as follows:

> Throughout the years of our long manufacturing experience we have devoted considerable attention to the importance of quality control and the benefits to be derived from this source. From time to time our method of control has been revised to effect improvements. One of the most recent changes which we have made is to introduce statistical analysis of our rejections.
>
> For each item rejected during the process of manufacture a form slip is made out which indicates the type of the product rejected, the department responsible for this rejection, the cause, the workman's clock number when the rejection is caused by faulty workmanship, and list value of the rejected items. Data from these slips are punched out on an International Business Machines card and sorted and summarized in the conventional manner so as to afford us a rapid analysis of the above-mentioned details regarding rejections. In this manner it is a simple matter to determine not only the value of our rejections for a given type of product, but also to determine the cause, whether it be a technical reason or one of faulty workmanship. In the case of faulty workmanship, this analysis assists us in determining the identity of those workmen who consistently turn out poor quality products.
>
> As a result of the introduction of this system, we have realized not only a decrease in our percentage over-all rejections, but we have also observed that our foremen and individual workers as well have become quality conscious. To a large extent the quality of the product can be brought back only by the quality consciousness of the individual worker, and we believe, therefore, that the clerical cost of such a system pays good dividends in this direction.

BENEFITS OF QUALITY CONTROL.—The available benefits of analytical and systematic control of quality in manufacturing may be summarized as:

1. Reduction of the costs of scrap, rework, and adjustment.
2. Reduction in the costs of the factors of production through random assembly, uninterrupted production, and greater utilization of labor and facilities.
3. Reduction in costs of inspection.
4. Improved attainable quality standards, with either higher market values for a given sales volume, or greater volume for a given price.
5. Lower cost designs of products and processes for a given product quality standard.
6. Improved technical knowledge, more reliable engineering data for product development and manufacturing design, and reliable characterization of the attainable performance of processes.

A guide to areas of first attack and to justifiable levels of expenditure for control is found in a calculation of the costs associated with at least the first category above. In emphasis, each one thousand dol-

lars of annual expenditure for analytical quality control is profitable if there can be maintained a reduction of shrinkage and rework costs of at least a like amount, since the less tangible savings add much to the margin.

Design-Control Approach to Manufacturing

DEVELOPMENT.—Early handicraft production was concerned with simple tools, incidentals to skills and preferences of individual craftsmen. Each unit of product was unique, meeting its maker's current judgment of utility, and was purchased after direct customer inspection and valuation in an environment of "buyer beware."

Modern manufacturing began with an emphasis upon the control of variability in quality characteristics, permitting random assembly and interchangeability. Subsequently, the stresses in a growing economy made essential the use of large-scale enterprises and volume utilization of fixed-capital investments. With mounting complexity of enterprise organization, and the problems of cost reduction and price competition, there arose a demand for professional managements with the approach of scientific method.

Quality control, however, has been viewed vaguely as a problem of process design, labor supervision, and screening inspection, approached in high scrap periods with a "do something about it" ultimatum, in periods of average scrap by acceptance of and allowance for the related costs. Modern quality control, through systematic observation and action, can refine and maintain existing processes for optimum performance. It completes the tools of scientific management for the three basic control problems—production (volume), cost, and quality (value).

DESIGN AND OPERATION.—Engineering defines the necessary performance standards for products and parts, processes, materials, tools, and workmanship, in terms of verifiable characteristics and economic degrees of uniformity. Both the product and the manufacturing "system" must be designed. It is desired that all cognizable factors function exactly as projected, **excluding all other possible factors.** But technical projections, operations, and measurements are not infallible. Designs and specifications of the factors of production are complex and rarely complete. Factors themselves are often unstable, designs are sometimes developmental in character, and the requirements are frequently ahead of current performance. With the momentum of mass operations and the all too prevalent insensitivity of operating controls, obscure departures from standards create pile-ups of scrap and hidden costs which insidiously establish themselves, by default of management, as normal and unavoidable burdens. In one company with an annual net production of $10,000,000, the generally accepted shrinkage of 20% in a precision product presented a loss at direct factory cost of such magnitude that analytical quality control was instituted. Each dollar expended therewith reclaimed fifteen dollars of scrap loss in the first year.

INSPECTION.—Generally speaking, the last step in a cycle of production is inspection, where strictly we may distinguish between an

operation of inspection which provides data, and a **judgment** or inference from the data as a basis for action. An obvious illustration is the inspection of a sample from a lot of parts, where judgment must be rendered regarding the quality of the lot, within an acceptable range of error, in order to take proper action. Even with complete or 100% inspection, this distinction is pertinent because of control, precision, and accuracy considerations of measurement itself.

Inspection has commonly been viewed as a necessary and costly evil for weeding out nonconforming units **after they are made.** Actually, it provides data for several purposes in a fully developed quality control program, such as:

1. Actions to dispose of specific lots of material:
   a. Release to customers or subsequent operations.
   b. Assign to rework operations.
   c. Assign to scrap.
2. Actions on manufacturing process:
   a. Accept a process without change.
   b. Identify and eliminate assignable causes of variation.
3. Action in cooperation with engineering to facilitate:
   a. Development of information on process technology and attainable quality control.
   b. Establishment of new standards and specifications.
   c. Rationalization of existing standards and specifications.

Note that it is desirable to segregate rework inspection so that the original records reflect control of quality actually manufactured.

From the functional viewpoint, the **works inspection department's authority** and responsibility are usually limited to action with respect to acceptance or rejection according to specified criteria at the various stages of manufacturing. Action with respect to control of quality, rationalization of standards and performance, and the design of sampling plans is usually in the hands of another department, i.e., the quality control department.

Acceptance Inspection.—Acceptance inspection provides action with respect to individual units (screening) and/or lots of material. **Acceptance sampling inspection** provides action on specific lots, based upon sampling plans and criteria designed for given risks of error. Complete or 100% inspection is the only true screening type, since with sampling inspection the defectives are removed only from the fraction of material inspected. It should also be noted that inspector accuracy is often below 90%; that some defects can get through even complete inspection, unless tandem inspection is used. Where sampling is in use, improved control allows reduction in the amount of sampling. **Inspector accuracy** is here defined in per cent as follows:

$$\frac{d_1 - d_2}{d_1 - d_2 + d_3} \times 100$$

where d_1 is the number of units reported as defective by the inspector; d_2, units reported defective and upon reinspection found to be acceptable; d_3, units accepted but later found defective.

Control Inspection.—Control inspection has for its purpose supervision and refinement of the control of quality. In some cases the informa-

tion obtained from acceptance inspection can be used for control purposes; in others, supplementary inspections are required, either temporarily for special investigations or permanently for supervision in critical areas. Control samples are usually small for measurements made on variables, and are taken in ways to bring out the effects of suspected assignable causes. When control inspection is on an attribute basis, the sample must be of a certain minimum size because of statistical limitations, generally considerably larger than samples used when working on a variables basis.

Inspection in the broader sense must be concerned with verifying the behavior and acceptability of all factors of production having influence on the product performance quality. These factors may be grouped as follows:

1. Incoming materials and components.
2. Manufactured parts and components.
3. Labor techniques and skills.
4. Machines and processes.
5. Tools, gages, and instruments.
6. Inspector performance.
7. Final product performance.

A distinction is made between performance and parts qualities. Engineering knowledge projects desired performance qualities, such as the speed characteristic of a motor, in terms of characteristics of parts actually manufactured, e.g., motor field punchings, coils, etc. Control of the final quality characteristics must be dependent upon control of the parts characteristics made. In some cases the engineering projection of relationship between performance and parts qualities may be in question.

Character and Completeness of Inspection.—The character of inspection or test is determined largely by the characteristics measured, required accuracy and precision, skill and training of inspection personnel, and general conditions of inspection. The types of inspection may be grouped as follows:

1. **Visual,** for identifying attribute defects and grades of quality where gages and instruments are not applicable, e.g., for scratches, dents, flaws, etc.
2. **Gaging,** of a go, not-go, character using dimension gages, signal test sets, or instrument scale limits, etc.
3. **Measurement,** where meters, micrometers, and other continuous scale devices are used.

The amount or completeness of inspection depends upon: control of quality, severity of requirements, amount of preceding and subsequent inspections, etc. As previously indicated, the amount of acceptance inspection can often be reduced from 100% to relatively small samples, as control is improved. The allocation of acceptance inspection along the production line, from incoming materials to final product, is made with regard to such considerations as:

1. Points where materials, parts, and assemblies enter or leave a departmental jurisdiction.
2. Points where quality characteristics to be verified are later concealed in assembly or processing, making conformance verification impossible.

3. Cases of nondestructive testing where control is at a level justifying the use of acceptance sampling in place of complete inspection.
4. Cases where the destructive testing requires control sampling and supervision for reliable acceptance judgment.

Of course, certain quality characteristics necessitate sampling inspection. In this regard the following quotation may be useful. (Control Chart Method of Controlling Quality During Production, American Standards Assn.):

It therefore follows that when the inspection test is destructive, and when therefore the marketed articles are not themselves inspected (but are instead represented in the sample of articles that are), it is particularly desirable that they be produced under conditions of statistical control so that the quality of the uninspected portions may be safely inferred from the results shown by samples.

The tabulation below is an exhibit of some quality characteristics for which 100% inspection of the product is practicable, and others for which, by necessity or economic reasons, sampling inspection alone is practicable.

A. Characteristics for which **100% inspection is practicable:**

Dimensions, subject to measurement or go and not-go gaging.

Performance characteristics, subject to nondestructive testing, such as the operating time of timers, the torque of motors.

Electrical characteristics, such as the gain of vacuum tubes, the resistance of relays.

Characteristics observable by visual inspection, such as assembly, finish, appearance, condition, or material defects; flaws in cloth or painted surface.

B. Characteristics for which **100% inspection is not practicable:**

Life tests, measuring a maximum period of usefulness, such as the life of electric lamps and fan belts.

Performance characteristics, subject to destructive testing, such as the firing of ammunition, blowing time of an electric fuse, the B.t.u. content of gas, fuel oil, and coal.

Ultimate physical properties, such as the tensile strength of steel, the bursting strength of boxboard, the torsional strength of steel rod, the tensile strength of welded joints of copper line wire; flash point and viscosity of oil.

CONCEPTION OF QUALITY.—The function of quality control has basically two phases: manufacturing control and coordination.

A production department must cope with variables at all points, and cost-wise prefers more liberal specification tolerances. The engineering department strives perhaps for more severe tolerances. However, for any given output, the cost of manufacturing increases as the permissible tolerance range of variation is restricted. If the severe tolerances are not met through effective control, the high fraction rejected at final acceptance inspection is costly. If they are met, the cost of operations becomes expensive. Between two extremes lies a minimum cost point for any given tolerance. It does not pay from the manufacturer's viewpoint to go to the point where differential cost exceeds differential market value.

Product designers must **recognize economic balance in setting tolerances** and understand the science of control. A quality control department not only must analyze performance and refine control of varia-

bility, but must also coordinate product and manufacturing engineering with attainable operations and results.

Analysis of performance requires more advanced methods and a broader viewpoint than can be provided in the specialized acceptance function of the usual inspection department. More professional personnel is usually necessary. Quality phenomena result from complex natural and physiological factors. Repetitive manufacturing no longer conceives a once-through operation illustrated in Fig. 1 (a), with inspection simply a screening mechanism, adding little to existing knowledge of control of the preceding operations. There must be cycles of successive approximation, suggested by Fig. 1 (b), where evidence is continually interpreted against working projections.

Symbolically, in Fig. 1 (b), the variations in manufacture of particular characteristics will appear as failures of the head of the inspection arrow to close exactly on the shaft of the specification arrow. These departures or variations must be interpreted statistically. As assignable causes are removed, the residual variability will represent optimum performance of the process. If the distribution of the latter leaves an uneconomic fraction outside the necessary specification limits, the variability is reducible only by revising the process.

Revision does not always call for large outlays. Consider a workman cutting 1-in. pegs from long dowels, using only rule, pencil and saw, and being able to so control the operation that the measured results do not indicate assignable causes present. Also assume that the resulting variability is too great, leaving 30% outside specification limits. Then consider the installation of a fixture with stop, clamp, and saw-guide. The former residual variability may now be reduced to meet the specification limits.

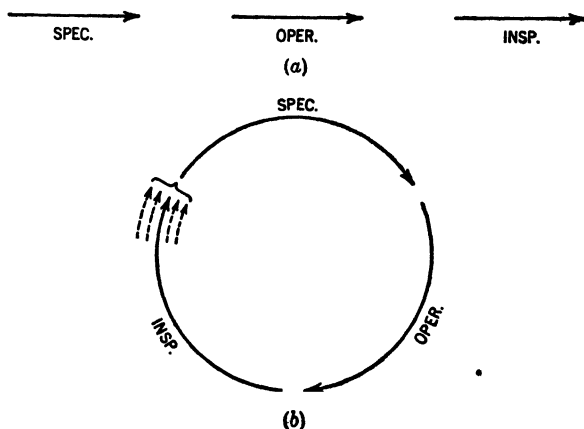



FIG. 1. Changes in the Conception of Inspection Brought About by Quality Control

The economy of revision investments must be rationalized by comparing its annual equivalent cost with the related change in scrap cost, etc. In some cases, where changes in specification tolerances are under the manufacturer's authority, it **may** prove to be better economy to **revise tolerances** rather than the process.

Organization for Quality Control

QUALITY CONTROL ORGANIZATION.—As stated, control problems can be attacked at an individual process or machine, by the individual process engineer or supervisor who commands both technical knowledge and elementary control techniques. However, with the obvious interdependence of incoming materials quality, process performance at various stages, and final product quality, over-all coordination soon becomes desirable.

In observance of the principle that authority and responsibility shall not be divided, representative opinion assigns direct control operations to the manufacturing operations section. In this case the central quality control department serves as **functional supervisor of control** and acceptance inspection until products leave final floor inspection. In some cases the control may extend further, even until the products have been delivered and are actually operating on the premises of the ultimate consumer.

In the smaller plant—or the larger plant in earlier stages of development—the process engineer on the floor can assume all functions. With larger plants and scope, it is more efficient to have a central staff possessing specialized training. The department should be directed by a high-grade executive engineer with authority equal to the manufacturing department superintendent. The specialized responsibilities within this department can be suggested as follows:

1. Standards and specifications coordination.
2. Process control methods and results.
3. Acceptance inspection methods.
4. Statistical research (a mathematical statistician).
5. Customer quality complaints.

DEVELOPMENT IN THE PLANT.—Those of us who have seen modern quality control in its ultimate development realize that our current problem is one of industrial education in approach and technique. We can review the growth of work simplification for a parallel. Correspondingly, programs of development and realignment should be applied gradually, allowing specific methods to adapt and to sell themselves fairly at each stage. Perhaps the following steps can be suggested:

1. **Preparatory and Educational Period**
   - 1.1 Acquisition of familiarity with control charts and other elementary statistical technique by one or two key process engineers.
   - 1.2 Application of control charts to one or two simple problems, say at existing inspection points.
   - 1.3 When successful, extension of technique to other problems in the same department, using experience of original inspectors.

2. **Formative Period**
   - 2.1 Set up steering committee for new methods, representing engineering, production, and inspection.
   - 2.2 Explain techniques and results obtained in preparatory experiences.
   - 2.3 Make a survey of critical quality and high scrap loss areas.
   - 2.4 Select a few new critical problems to be approached on larger scale.
   - 2.5 Provide talks for operators concerned—selling technique to them as their tool; get cooperation.
   - 2.6 Institute plant class in statistical methods.
3. **Plantwise Operating Level**
   - 3.1 Set up quality control department in which there are men experienced in both process technology and statistical methods. This department should have functional responsibility for control and inspection methods; direct responsibility for product acceptance and coordination. The department manager should report to the plant manager.
   - 3.2 Set up clinical class meetings on problem developments and new techniques. Make reports on dollar savings and quality improvements.

QUALITY CONTROL DEPARTMENT.—In view of the broad responsibility for investigation and coordination assigned to it, the quality control department should be independent of the specialized interests of sales, engineering, manufacturing, and inspection departments. Because of the costs of failure to act promptly upon instabilities that may threaten a process, this department should be given authority to halt unsatisfactory operations when necessary, and should report directly to an officer of the company. Also, with the need for impartial judgment in assessing responsibility for failures to meet standards, and in arbitrating borderline cases of acceptability, this department must have functional authority over the **adequacy** of inspection procedures.

In summary, a quality control department should have **authority** and responsibility for:

1. Adequacy of methods and records of acceptance inspection; design and assignment of sampling plans; judgment of borderline case of quality characterization.
2. Establishment of control inspection at strategic points; investigation of and action upon assignable causes of variation in quality characteristics.
3. Summary action on materials, machines, and processes, when their departures from standards endanger the acceptability of product.
4. Coordination of specifications, operations, and results for optimum joint economy of volume, cost, and value.

In the sense that this department is the **control link** in the quality cycle of manufacturing, Fig. 1 can be drawn functionally as shown in Fig. 2. The inspection segment here represents acceptance verification only, and should be part of the quality control department. This plan puts on the manufacturing department the responsibility for turning out only good products. Also it provides an incentive for the manufacturing department to cooperate with the quality control department, since with better control the latter may grant sampling inspection, thus reducing inspection costs in the manufacturing group.

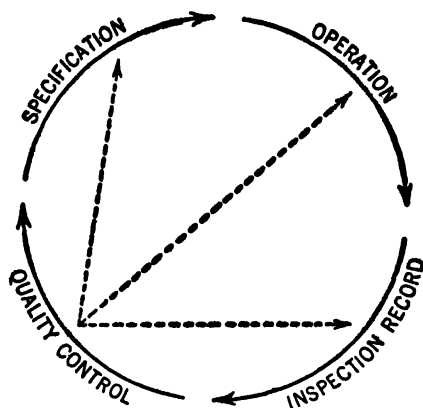



FIG. 2. Functional Relationship of Quality Control

Statistical Presentation and Control Methods

DISTRIBUTIONS AND LIMITS.—In understanding the control problem it is necessary to recognize that natural phenomena and their relationships are statistical in character, i.e., that no two elements are alike and that an aggregate of observations will compose a scatter or distribution, given a sufficiently sensitive method of measurement. The results of repeated productive operations, e.g., one measurement on each of n things, will provide a distribution of values. Similarly, n repeated measurements on the same thing will provide a distribution because of the inherent characteristics of the method of measurement. In some cases, however, the scatter may be too small to be apparent with the precision of a particular method of measurement, or to be pertinent to the requirements of a particular problem.

Such variations arise from a complex of causes, some of which may be assignable or detectable in their effects, and others which are so numerous and infinitesimal that their individual effects are indistinguishable. The effects of the latter group are described as chance variation for a given operation and method of measurement, and provide the basis for statistical criteria by which we judge the presence of the former type of cause.

The condensation of observations into a distribution for characterizing a system of variability may be of little value unless the data are good in the first place. To be good, data must derive from essentially the same conditions of operation and measurement, i.e., must arise from a common universe of chance causes. Such a set or series of observations is said to be homogeneous, or in statistical control.

Assuming for illustration that we have a state of control, the relationship of distribution to specification limits is shown in distribution A in

Fig. 3, with the diameters of 1,000 screw-machine parts. Data used in plotting the curves are given in Fig. 4. The scale of values, X, has been divided into cells or segments and the frequency with which observed values appeared in each cell has been noted. (For techniques in presenting data see Manual for Presentation of Data, American Soc. for Testing Materials.) It is apparent, although the data were homogeneous in the sense of uniformity, that they were at the wrong level.

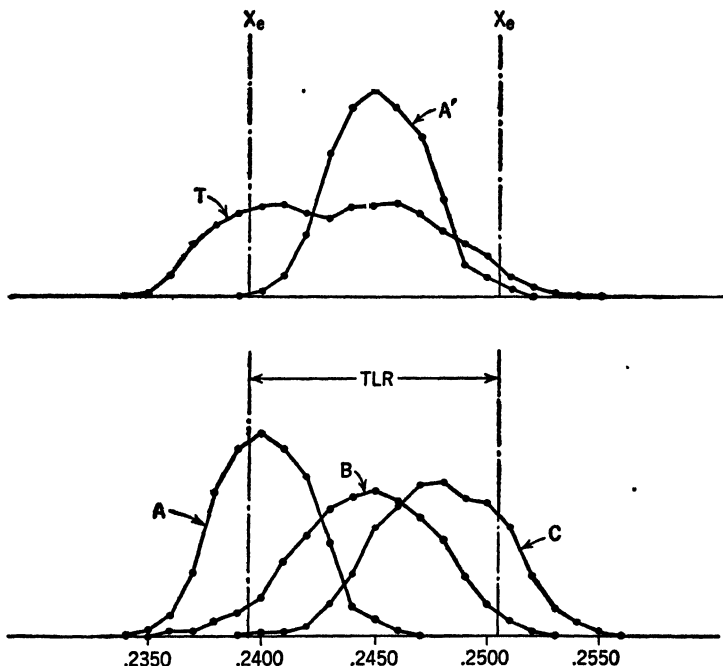



Fig. 3. Distribution of Inspection Observations in Relation to Specification Limits

Limits X_e illustrate current specification requirements. Parts outside these limits are **defective,** those inside **effective.** In a particular lot of parts, the collective **lot** quality can be described in terms of fraction defective, rather than the distribution, but with some loss of information.

It is obvious that we are concerned with at least two characteristics of the pattern of variation: the **location** of the mean or center of gravity of the distribution; and the spread or dispersion. Both influence the fraction defective. In this case, perhaps an adjustment of the machine would locate the average nearer the midpoint or **bogey** of the specifica-

Cell Midpoints	A	B	C	Total		
.2350	4			4	.0014	1
.2360	17	2		19	.0064	6
.2370	56	2		58	.0193	19
.2380	127	13		140	.0467	47
.2390	168	22		190	.0633	63
.2400	181	35	1	217	.0723	72
.2410	169	65	3	237	.0790	79
.2420	142	91	8	241	.0803	80
.2430	85	111	27	223	.0743	74
.2440	28	124	54	206	.0686	69
.2450	18	127	91	236	.0786	79
.2460	5	120	114	239	.0796	80
.2470		108	134	242	.0806	81
.2480		85	136	221	.0736	74
.2490		54	123	177	.0590	59
.2500		28	120	148	.0493	49
.2510		11	96	107	.0357	36
.2520		2	52	54	.0180	18
.2530			25	25	.0085	8
.2540			11	11	.0038	4
.2550			5	5	.0017	2
	1,000	1,000	1,000	3,000	1.0000	1,000

FIG. 4. Data from Which Fig. 3 Was Plotted.

tion limits, with a reduction in the fraction defective, as suggested in Fig. 3 by relocating A at A'. Also, any reduction in the actual spread or dispersion would lower the fraction outside limits; would in fact ultimately permit narrower design limits. But under the assumed conditions of control there are no assignable or detectable causes to be removed, and the dispersion present cannot be reduced except by redesign of the process.

STATISTICS OF OBSERVATIONS.—As indicated, there are at least two distribution characteristics of interest. These are evaluated by **statistics,** or functions, of the observed group of values. In most practical cases, location is defined by the arithmetic mean:

$$\bar{X} = \frac{X_1 + X_2 + X_3 + \ . \ . \ . \ X_n}{n} = \frac{1}{n}\sum_{i=1}^{i=n} X_i$$

where X_1, X_2, etc., are the observed values, and n is the number of observations. Dispersion or spread can be characterized by one of two commonly used statistics, the **range** and/or the **standard deviation.** The range is defined as the absolute difference between the largest and smallest values in the set:

$$R = (X_{max} - X_{min})$$

The standard deviation is defined as the root-mean-square of the deviations of the values from the arithmetic mean of the set:

$$\sigma \text{ (sigma)} = \sqrt{\frac{(X_1 - \bar{X})^2 + (X_2 - \bar{X})^2 + \ldots + (X_n - \bar{X})^2}{n}}$$

which can be rearranged algebraically for easier calculations as:

$$\sigma = \frac{1}{n}\sqrt{n\Sigma X^2 - (\Sigma X)^2}$$

where ΣX^2 represents the sum of the squared values of X, and $(\Sigma X)^2$ the square of the sum of the values of X.

However, the standard deviation is preferable in control work, except in the smaller groups of observations, say less than 15, since the range is based upon extreme values only and utilizes too little of the information available.

When the group of observations is fairly large, calculations of these statistics directly from the original observations is laborious. In such cases a shorter method of calculation from a grouped frequency distribution is available. (For this and other elementary statistical methods see Manual for Presentation of Data, A.S.T.M.)

Information Contained in $\bar{X}$ and σ.—The **total** information contained in the observations of Fig. 3 can be presented only by giving all of the originally observed values. Properly used, a frequency distribution reduced to **relative frequencies** (relative frequency of a cell is the ratio of its frequency to the total number of observations) will give practically all of the total information. If we report merely the fraction of the observations outside specified limits, the portion of the total information presented is very small. If we report the arithmetic mean and the standard deviation, even if we know nothing about the form of the distribution, a reasonable amount is presented. Tchebycheff's theorem tells us, with no reservations whatever, that a fraction equal to or greater than $\left(1 - \frac{1}{t^2}\right)$ of the total number of observations lies within the closed range $\bar{X} \pm t\sigma$ (where t, the number of standard deviations used, is not less than 1). If $t = 3$, more than 88.9% lie within the zone $\bar{X} \pm t\sigma$. In illustration, a group of 300 pin lengths had $\bar{X} = .7429$ and $\sigma = .00333$. We know that approximately 89% or better of these were within the limits: $.7429 \pm 3\ (.00333) = .7329$ and $.7529$.

When there is evidence of controlled conditions, the percentage of total observations within the zone $\bar{X} \pm t\sigma$ can safely be reported to be much higher. An approximation can be made from the normal distribution (see any representative text on statistical methods) from which the following percentages are derived:

t	% Within $\bar{X} \pm t\sigma$
1.0	68.27
1.5	86.50
2.0	95.45
2.5	98.80
3.0	99.73

OBSERVATIONS UNDER UNCONTROLLED CONDITIONS.—If we have a process of operation afflicted with assignable or detectable causes of variation, successive samples or groups will tend to cluster at levels (averages) and with degrees of dispersion that differ **between groups** by more than chance or nonassignable causes allow.

In general, statistical theory is built upon the variability of observations derived from a controlled system. When the system is not controlled, i.e., there is in effect a series of systems because of assignable causes, we use statistical theory for criteria to indicate the presence of these causes. Shewhart uses the illustrative device of a large bowl of tags or chips, numbered to provide some distribution of values as a parent universe, to illustrate the behavior of sampling under controlled conditions. If repeated draws and observations are made of single chips, with replacement after each draw, and if the **operation** of sampling is **random**, the resulting observations in the sequence will vary randomly, and will in the long run compose a distribution matching that in the bowl. Any part of such sequence may provide a distribution related to that of the universe of the bowl, differing from it by chance effects of sampling. (For complete discussion see Shewhart, Statistical Method from the Viewpoint of Quality Control, Graduate School of Dept. of Agriculture.)

To illustrate the effects of the assignable causes, assume that another bowl was substituted secretly, with different distribution, mean, and dispersion. The next resulting sequence would appear with different level and spread. After a given number of observations were made, still another bowl could be substituted, and so on. The results of such drawings, with 1,000 in each sequence, are illustrated in Fig. 3, in curves *A*, *B*, and *C*. If in ignorance we made a composite distribution, we would have distribution *T*. The latter has been reduced proportionately to a basis of 1,000 readings for proper comparison. This can be compared with curve *A* in its adjusted location *A'*. Control of the order of *A'* in place of *T* would reduce the outside limit fraction from 20.4% to 5%. If the original position of *A* had been maintained, the outside limit fraction would be about 55.3%.

It is obvious that the presence of the assignable causes of change of bowls has destroyed the degree of controlled behavior expected, and that any accumulated sequence would have unpredictable mean and dispersion as well as a greater dispersion and a larger fraction of values outside specification limits than may have been predicated upon relatively controlled conditions. Conversely, removal of assignable causes not only reduces dispersion and outside-limit variation, but also allows centering the residual variability between the specified limits.

In actual cases these **changes in conditions or "bowls" may occur frequently or infrequently**, and in many complex ways. Assignable causes may create systematic departures from expected level, or may come and go haphazardly to confuse any casual interpretations of results for the presence of removal causes.

CONTROL CHARTS.—Through the work of mathematical statisticians, centered principally about Dr. W. A. Shewhart (Economic Control of Quality of Manufactured Product), we have simple methods for control supervision and detection of lack of control. For technical reasons these methods employ means, ranges, standard deviations, or

fractions defective of groups of observations rather than single observations directly. The methods lay emphasis upon the order of the observations, where is meant order with respect to time, place, source, etc., which may be of significance with respect to known conditions under which the observations were obtained. The following quotation (Manual for Presentation of Data, A.S.T.M.) is of value describing the methods:

For a constant system of chance causes, the averages, $\bar{X}$, the standard deviations σ, the values of fraction defective, p, or other functions of the observations of a series of samples will exhibit statistical stability of the kind that may be expected in random samples from homogeneous material. The criterion of the quality control chart is derived from laws of chance variations for such samples, and failure to satisfy this criterion is taken as evidence of the presence of an assignable cause of variation.

As applied by the manufacturer to inspection data, the control chart provides a basis for action. Continued use of the control chart and the elimination of assignable causes as their presence is disclosed by failures to meet its criterion tend to reduce variability and to stabilize quality at aimed-at levels. While the control chart method has been devised primarily for this purpose, it provides a simple technique and criterion that has been found practically useful in analyzing and interpreting other types of data.

It is beyond the scope of this presentation to provide an adequate discussion of the statistical methods in production quality control, and in engineering and research problems. These methods have been integrated with the work of practical quality control and are available for application to actual industrial processes (Guide for Quality Control and Control Chart Methods of Analyzing Data, Z1.1 and Z1.2; Control Chart Method of Controlling Quality During Production, Z1.3, American Standards Assn.). Other references on quality control are given subsequently in this Section.

Works Inspection Record and Breakdown

WORKS INSPECTION RECORD.—This type of inspection is commonly performed on a go, not-go basis, employing gages, signal test sets, or measurement instruments with limits marked upon the scales. The test operation merely sorts the units of product according to conformance or nonconformance to limits, i.e., good or bad, recording the number inspected and the number rejected. When there are two or more characteristics tested on each piece, it is highly important to record a breakdown extension of total rejections, showing the number of rejections by characteristic. If each unit is rejected upon the first defect found, the sum of entries in the breakdown will equal the total rejections entry. If every piece is inspected for all characteristics, the sum will exceed the total-rejections entry. The former practice is more usual.

Fig. 5 illustrates a common form of works inspection log sheet for original record. Such inspections and records are usually maintained both for final assemblies and for parts earlier in the process. In assemblies, the characteristics inspected are often performance qualities resulting from the joint functioning of qualities of the component parts.

ORIGINAL LOG SHEET FOR ATTRIBUTE INSPECTION
(For 100% Inspection)

Material____________________

Part No.____________________

Department____________________

Date	Code or P. No.	Lot Size	No. Rej. Parts	Fract. Rej. Parts	No. Defects Each Type	Inspector Clock No	Remarks Number

REMARKS:

FIG. 5. Typical Works Inspection Log Sheet for Original Record

CONTROL SUPERVISION.—In some cases there is available a direct line of reasoning from actionable departures from expected levels of fractions defective to some contributing classification in the breakdown, and directly therefrom to more obvious explanatory causes recognized by the operating personnel. For example, a rise in assembly rejections may obviously be due to a spindle projection, which in turn may be seen immediately to be due to the drift in a machine control-stop.

However, it is usually inefficient to rely upon intuitive and casual interpretations of the **numbers** of rejections appearing in the inspection record. First, it is noted that lots or samples may vary in size, and direct scrutiny of variations in the **numbers** alone may not permit reliable judgment. Fractions defective provide a more comparable and dependable index. Second, the observed fractions in a sequence will vary at least due to chance effects described earlier, and economic control criteria are necessary for reliable identification of variations due to assignable causes in the process.

CONTROL CHARTS.—The statistical quality control chart provides an efficient technique for this purpose. Effort is conserved by restricting emphasis to those departures from current control standards that promise effective investigation. The details of their construction are provided in the American Standards Assn. standards referred to above.

Basically, the chart for fractions defective consists of two features: a center or expectation line of average fraction defective, $\bar{p}$; and control

limits, at a distance of three standard deviations on each side of the center line.

$$\text{Center line} = \bar{p}$$

$$\text{Action limits} = \bar{p} \pm 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

where n is the number of units actually inspected, and $\bar{p}$ is the weighted average fraction defective derived from representative past results used for analysis. In some cases a standard p' is used in place of $\bar{p}$, established as a desired or aimed-at value designated by specification.

Ordinarily, the control chart for p is most useful when samples are large, say greater than 50, more specifically when np is greater than four.

In general, the appearance of plotted points (fractions) outside control limits indicates that an assignable cause has entered to change the process from the state assumed to exist in setting the standard; i.e., indicates that investigation is appropriate. However, even though points all fall within limits, indications of trouble or change may be evidenced by unusual pattern. Three criteria for detecting lack of control are:

1. A sequence of points close to one limit or the other.
2. A long sequence, say more than 5 or 6, above or below the center line.
3. A sequence of points suggesting trend upward or downward.

Shewhart discusses these supplementary criteria in "Contributions of Statistics to the Science of Engineering" (Univ. of Pa. Bicentennial Conf., Volume on Fluid Mechanics and Statistical Methods in Engineering).

Although much can be accomplished through the use of such attribute data from inspection, the causes of uncontrolled variability are often obscure and complex. Therefore, when assignable causes are not identifiable directly through study of components of the breakdown, it may be necessary to move back in the process for supplementary control inspection, perhaps by variables measurements. Such progressive analysis, "climbing the tree" of the manufacturing flow layout, may lead back in some cases to incoming raw material. In other cases it pays to reach back to vendor suppliers, cooperating with them in a joint control program. Ultimately, it may be advantageous to accept the control records of a supplier as evidence supporting reduced incoming material inspection.

During the early stages of a newly applied program of quality control, psychological factors often bring about a reduction in the running average level of fraction defective without formal identification of causes of variability. Control limits often are not used on the plotted fractions until an approximately stabilized level emphasizes a need to distinguish between points at that level. In any case, as assignable causes are removed the average fraction will trend downward to lower levels. In such cases the central line and control limits of the charts are revised periodically to conform to the conditions expected to hold in the immediate future.

Example for Fraction-Defective Charts.—In illustration of control supervision with works inspection records, the data in Fig. 6 have been summarized from the inspection records of a precision control device.

PRODUCT: Control Device DRAWING NO.: D11807 DEPARTMENT: 870-6
AMOUNT INSPECTED: 100% INSPECTION LOG REFERENCES: ____________

Lot No.	Lot Size	Gross Def.		A (1 Item)		B (1 Item)		C (6 Items)		D (5 Items)		E (8 Items)		F (Others)	
	N	r	Fract.	r	Fract.	r	Fract.	r	Fract.	r	Fract.	r	Fract.	r	Fract.
1	2,999	599	.200	103	.0344	131	.0437	73	.0244	67	.0224	49	.0163	176	.0588
2	3,237	537	.166	98	.0303	98	.0219	49	.0151	83	.0256	38	.0117	171	.0512
3	3,156	457	.144	101	.0320	36	.0114	66	.0209	99	.0314	23	.0073	132	.0418
4	3,423	623	.182	156	.0455	62	.0181	68	0198	142	.0415	45	.0131	150	.0438
5	3,727	727	.195	146	.0391	63	.0169	94	.0252	154	.0413	55	.0147	215	.0577
6	4,263	763	.179	168	.0394	43	.0101	135	.0317	138	.0324	71	.0167	208	.0488
7	3,687	487	.132	80	.0217	38	.0103	41	.0111	79	.0214	24	.0065	225	.0610
8	2,881	676	.234	235	.0815	23	.0080	58	.0201	77	.0267	99	.0344	184	.0638
9	2,262	562	.248	211	.0931	39	.0172	65	.0287	132	.0582	18	.0079	97	.0428
10	2,922	697	.248	234	.0799	94	.0321	96	.0328	90	.0308	31	.0106	152	.0520
11	3,785	875	.231	240	.0634	138	.0364	93	.0246	95	.0251	104	.0274	205	.0542
12	4,814	914	.190	207	.0430	104	.0215	142	.0294	111	.0230	67	.0319	283	.0588
13	2,159	359	.166	84	.0390	44	.0204	55	.0255	50	.0232	20	.0043	106	.0515
14	3,089	484	.157	56	.0189	98	.0317	54	.0175	55	.0178	34	.0110	187	.0605
15	3,156	616	.175	187	.0532	46	.0139	62	.0177	80	.0228	51	.0145	190	.0602
16	2,139	434	.203	110	.0515	36	.0168	45	.0210	56	.0262	12	.0056	175	.0818
17	2,139	503	.194	93	.0359	84	.0324	42	.0162	109	.0421	37	.0143	138	.0533
18	2,510	487	.194	98	.0390	45	.0179	57	.0227	59	.0235	51	.0203	177	.0705
19	4,103	803	.195	197	.0480	121	.0295	92	.0224	150	.0365	39	.0095	204	.0497
20	2,992	547	.183	163	.0545	45	.0150	79	.0264	51	.0170	26	.0087	183	.0612
21	3,545	555	.156	107	.0302	57	.0160	80	.0226	60	.0236	21	.0070	230	.0649
22	1,841	401	.218	65	.0353	40	.0217	27	.0147	132	.0716	18	.0098	119	.0646
23	2,748	418	.156	115	.0419	26	.0095	78	.0284	36	.0131	15	.0054	148	.0539
24	3,924	667	.170	141	.0351	59	.0150	144	.0367	55	.0140	24	.0061	244	.0622
25	2,056	319	.155	82	.0399	29	.0141	21	.0102	20	.0097	16	.0078	151	.0734
26	3,650	474	.130	74	.0203	65	.0178	80	.0219	80	.0219	51	.0140	124	.0340
27	4,001	535	.134	144	.0360	28	.0070	40	.0100	96	.0240	36	.0090	191	.0477
28	2,950	379	.128	88	.0298	38	.0129	74	.0251	50	.0169	24	.0081	105	0356
29	3,162	550	.173	158	0499	54	.0171	82	.0259	82	.0259	35	.0110	139	.0439
30	3,827	483	.126	134	.0350	42	.0110	69	.0180	58	.0152	24	.0063	156	.0408

FIG. 6. Inspection Data Summary on a Control Device

The gross number of devices defective is enumerated for each lot, together with the fraction it represents. Items A through E are groups of individual characteristics of similar nature for which the group numbers and fractions defective are given. Item F represents all remaining components of the breakdown.

In Fig. 7 are control charts prepared for these items. The central lines and control limits for the second 15-lot period are based upon the historical record of the first period. These were projected at the end of the first period to judge the results of the second, as they appear.

It is apparent that despite the fact that some points in the total fraction chart do not appear actionable, e.g., #16 through #19, reference to component item charts indicates that action is feasible in one direction or another. In this case consultation of individual entries on the inspector's breakdown led to identification of causes upon which work was done. In other cases additional studies by variables were necessary to trace removable causes of variability.

It is seen that improvement results during the second period. Therefore, for the third period beginning with point 31, a new set of central lines and control-limits was computed in most of the component groups and, by summation of their central line fractions, for the total fraction chart.

Later developments of this problem brought a high degree of control with an ultimate average fraction defective of about 6%. Further reduction of level could be accomplished only by redesign of a few of the processes for parts, since the residual variability in these cases was too great for the required specification limits.

Process Control with Measurements on Variables

CONTROL CHARTS BY MEASUREMENTS.—As demonstrated, go, not-go gaging, and classification do not provide as much information for control supervision as direct measurement of a variable characteristic itself; e.g., gaging the diameters of pins for fractions defective contrasted with micrometer measurements for actual variability. Usually we must move back from gaging inspection supervision, outlined in the previous example, to one or more stages of processing to identify and characterize variable process factors. For example, lack of control of heating-gas pressure at a wire-drawing die may influence the variability of diameter and stiffness, which causes bad control of width and thickness in a ribbon rolled from the wire, and in turn bad performance of an electric control device.

In many cases, there are numerous underlying factors, all initially suspected of uncontrolled contributions to the ultimate quality characteristics produced. In a specific problem it is particularly useful to list possible offenders, as a guide for designing the sampling for identifications of those factors out of control.

It has been indicated that the assignable causes of lack of control, i.e., avoidable variability in a given process, appear in both erratic and systematic ways. In terms of a control chart, erratic incidences appear as occasional "bad" runs and points; systematic and progressive effects as levels of points consistently above or below a central line, and as trends.

INSPECTION RECORD ON 11807 BY (p)

FIG. 7. Control Charts Prepared

from the Data in Fig. 6

Influence of Machine Layout.—With a single machine or process, both types of effect may occur. Because of the flow of units of work through the same "exposure" in this case, where the assignable causes can potentially operate on all units of product, this is designated as a **series** situation.

Where there are batteries of machines doing supposedly the same thing, e.g., screw machines producing to the same part specification, multiple spindles, etc., the situation is designated as a **parallel** one. The flows from these machines would ordinarily blend in a common flow. Obviously lack of control and excessive dispersion in samples from the common flow may be due to individual machines out of control, or to **systematic differences** between machines, as suggested by the bowl sampling illustration in Fig. 3. Not only would it be necessary to identify uncontrolled machines quickly, but a reduction of systematic differences would decrease the variability in the quality of the common product flow.

Observation for Control Supervision.—When taking observations for control supervision, where the samples are relatively small, a form simi-

ORIGINAL LOG. SHEET FOR MEASUREMENTS BY VARIABLES
(Special Control Studies)

Material or product: ______ Part Number: ______
Characteristic measured: ______
Unit of measurement: ______
Department: ______
Data recorded by: ______ Checked: ______

Series No.	Source: Date, hour, lot, etc.	Measurements on Items in Sample					Aver. for Series	Range or Stand. Dev.	Other Information
		a	b	c	d	e			

FIG. 8. Typical Form for Taking Observation Where Samples Are Relatively Small

This sheet may be used for such data as (a) Measurements taken in the course of regular inspection (variable basis), the measurements recorded being, for example, the first five taken in each hour. (b) Measurements especially made on a few items of a product otherwise regularly inspected by a go-not-go gage. Such special measurements may give valuable information on causes of excessive rejections. Under "other information" record machine, operator, or other relevant information that might be useful in tracing cause of peculiarities in certain subgroups.

lar to that in Fig. 8 can be used. This permits both a record of original readings and easy computations of average means and ranges used for setting control chart standards.

An essential feature of control chart methods is the segregation of data into **rational subgroups** or samples, **identified in order of production or source.** These groups are such that **variations within the groups** may be considered to be due to nonassignable or chance causes only, and **differences between the groups** may possibly be due to assignable causes. Such subgrouping is possible when the control engineer has technical familiarity with the problem. It is apparent upon reflection that the average range, from equal subgroups for example, or an average standard deviation, will permit approximation of the dispersion due to chance variability, without much influence from assignable displacements **between subgroups**; thus permitting the calculation of limit criteria that will identify variations in plotted points not due to chance.

As stated, subgroups for measurements of variables are preferably small, say 4 or 5, taken frequently when control is not stable, less frequently as control becomes established. One advantage of small subgroups is the greater sensitivity of group means, etc., in response to the presence of an assignable cause affecting perhaps only one observation therein.

It is usual to employ a chart for means together with one for either ranges or standard deviations. In many cases, particularly in mechanized processes, the latter chart will be in good control and can be subsequently omitted.

WIRE SPRING ILLUSTRATION.—A fine wire spring was required, as specified in the drawing of Fig. 9. Note that this specification is rather incomplete; that the right angle with the axis of dimension (a) is merely implied; that dimension (b) of the short leg is referred to the somewhat ideal form of the first loop.

The helixes were first wound intermittently on a small mandrel, with straight-wire connecting links. The connected helixes were then fed off the mandrel, one at a time, the projecting long leg of the end helix bent down by the operator's index finger, and the short leg cut by a blade positioned from what appeared to be the end-loop of the helix. The dimensions were then checked on the template of an optical projection comparator, using hourly samples of four.

The means and ranges for a single machine and operator are shown in Fig. 10, for short and long legs. As a first step, the historical period was developed in the first 25 samples, plotting points without limits. From this period, average means and ranges were used for computing statistical standards of central lines and control limits.

In the case of short-leg means, the sequence level or grand average was obviously very close to bogey of specification limits and the specification limit midpoint was therefore used for a central line. This is desirable in such cases. Where the level is appreciably different from bogey, it is better to use a grand mean central line so that control can be judged, aside from level; and the more actionable points distinguished from the others. Otherwise all points would call for action where there may be very few, if any, causes to investigate, except that creating a systematic displacement of level.

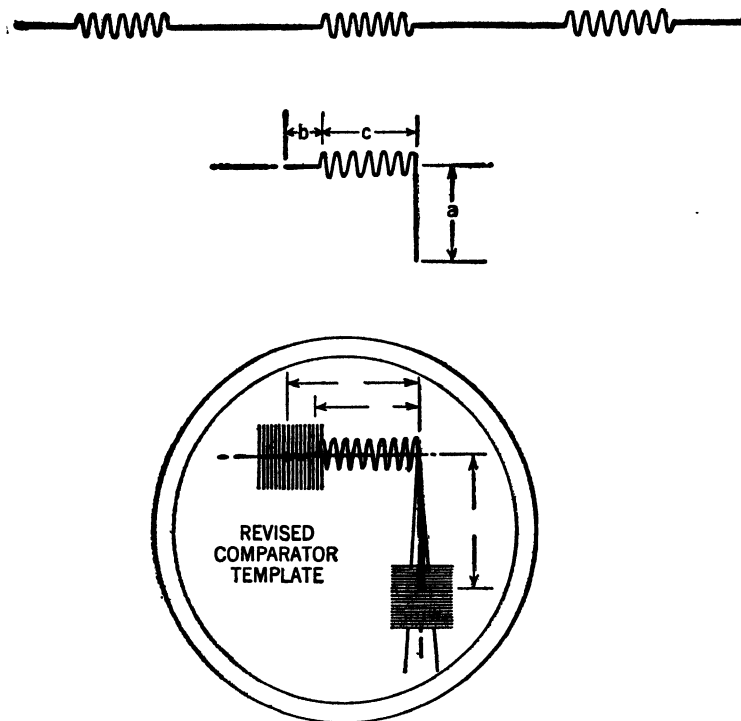



FIG. 9. Drawing of Spring on Which an Inspection Study Was Made

The statistical standards of central lines and central limits, computed as above stated, were projected into the then future period of another 25 points, in Fig. 11. It is usually held more desirable to have up to 25 points in the historical or qualifying period before projecting a statistical standard. However, in the earlier stages of a problem, a shorter sequence is permissible. As each sample was taken thereafter, the mean and range were easily calculated and plotted on a chart hung near the operator.

Conditions Discovered by the Study.—When the first statistical standards were computed, and also projected back over the past 25 points of the historical period for initial judgment of the process, several conditions were suggested, as follows:

1. The short-leg means were at or near the correct level of specification limit bogey, or midpoint, but displayed slight trouble in one point outside limits and in a tendency to trend in points 4 to 10, inclusive.

(Sample Size $n = 4$. Machine No. 1)

Sample No.	Short Leg		Long Leg		Sample No.	Short Leg		Long Leg	
	Mean	Range	Mean	Range		Mean	Range	Mean	Range
1	.0432	.0238	.1262	.0287	75	.0370	.0062	.1514	.0259
2	.0399	.0141	.1570	.0450	76	.0437	.0030	.1559	.0197
3	.0302	.0117	.1356	.0260	77	.0346	.0080	.1653	.0430
4	.0384	.0030	.1307	.0600	78	.0386	.0154	.1529	.0254
5	.0405	.0096	.1358	.0269	79	.0382	.0079	.1554	.0153
6	.0399	.0191	.1356	.0201	80	.0367	.0109	.1413	.0286
7	.0383	.0209	.1370	.0323	81	.0376	.0076	.1600	.0532
8	.0411	.0115	.1459	.0440	82	.0425	.0036	.1731	.0352
9	.0432	.0130	.1497	.0150	83	.0411	.0085	.1639	.0270
10	.0435	.0054	1463	.0387	84	.0407	.0040	.1604	.0097
11	.0437	.0305	.1498	.0245	85	.0395	.0087	.1485	.0336
12	.0385	.0110	.1277	.0516	86	.0370	.0140	.1554	.0179
13	.0368	.0101	.1475	.0300	87	.0434	.0087	.1718	.0515
14	.0419	.0170	.1509	.0222	88	.0351	.0075	.1540	.0251
15	.0390	.0138	.1523	.0144	89	.0392	.0102	.1547	.0185
16	.0477	.0173	.1379	.0156	90	.0386	.0036	.1538	.0458
17	.0421	.0199	.1705	.0553	91	.0395	.0102	.1542	.0314
18	.0443	.0073	.1442	.0179	92	.0420	.0070	.1655	.0594
19	.0250	.0142	.1350	.0775	93	.0405	.0131	.1426	.0175
20	.0420	.0067	.1563	.0356	94	.0368	.0036	.1616	.0218
21	.0401	.0134	.1612	.0143	95	.0434	.0096	.1486	.0415
22	.0446	.0188	.1557	.0299	96	.0414	.0060	.1578	.0090
23	.0369	.0143	.1396	.0491	97	.0382	.0135	.1673	.0231
24	.0470	.0113	.1382	.0220	98	.0406	.0098	1575	.0280
25	.0378	.0063	.1340	.0371	99	.0376	.0034	.1639	.0487
Sum	1.0047	.3440	3 6006	.8337		.9835	.2030	3 9468	.7558
Average.........	.0402	.0138	.1441	.0333		.0393	.0081	.1578	.0302

Fig. 10. Control Inspection Measurements on Spring Leg Lengths (Spring shown in Fig. 9)

FIG. 11. Control Charts Developed from the Data in Fig. 10

2. The short-leg ranges were in control, but at too high a level, $\bar{R} = .0136$ which indicated a dispersion of individual values that would have high shrinkage or scrap.
3. Long-leg means are at a level (.1441) far below the desired bogey, and show lack of control by a point outside limits and considerable trend in points 4 to 11, inclusive.
4. Long-leg ranges are reasonably in control, and at a level of $\bar{R} = .0333$. This suggests possibility of a low shrinkage per cent if control of means were obtained at proper level.

In connection with item 2 above, approximation of the **attainable** universe of single observation variability in the process is possible by $\bar{R}/d_2 = \hat{\sigma}$, where d_2 is a factor in tables of the A.S.A. manuals, and $\hat{\sigma}$ is the approximation of a standard deviation for σ'. By dividing the half-range of the specification tolerances limits by $\hat{\sigma}$, to give $t = (X_{s1} - X_{s2})/2\hat{\sigma}$, we can get from the t table on page 691 an approximation of the long-run fraction of product that would be acceptable if control is obtained.

Corrections Introduced.—The systematically low level of long-leg means was at first puzzling, since a supplementary control investigation of the initial coil-forming operation demonstrated that the **average** spacing between coils on the mandrel was correct. Upon examination of the projection-comparator inspection it was immediately apparent that the long legs were being bent in an inconsistent manner to angles varying from 45 to 80°, instead of 90°. The inspector was measuring only the leg-tip distance perpendicular to the axis of the helix. A tool fixture was designed to remove this effect, i.e., the process redesigned. Also, both product and inspection specifications were made more objective by requiring angle limits on the long leg, which were in turn placed on the comparator template. Here an assignable cause due to poor specification was removed. Thus, the long-leg systematic difference of means from bogey would be corrected, and with the improvement in the process the **degree** of variability (level of range) would be reduced. The erratic condition indicated on the chart of means was found to be due partly to spotty wire, which affected the degree of variability in spacing by the coil winder, and partly to inconsistence in operator application. The former factor was worked upon and improved. The latter was due to skill requirements on fine work at the limit of controlled human performance. Use of fixtures, and other aids, improved the condition.

In the case of the short legs, the cutting operator did not have a well-defined reference loop from which to reference the cutting blade, and the inspector likewise had difficulty in referencing the measurement. In processing, the end loops were smaller, in some cases not clearly definable. Specification dimensioning was revised, in terms of actual functioning of the part, referencing all dimensions from the apex of the long-leg tolerance angle limits.

After these steps, correcting for assignable causes in specifications, operations, and inspection, considerable improvement was obtained. The charts for a third period, points 76 to 100 inclusive, are shown in Fig. 11. Control was attained at proper **levels.** The **degree** of variability was reduced to a point where very few units of product were outside specifi-

cation limits. Control inspection was here used for acceptance inspection as well, and because of ultimate **stability** of the control, sampling was stretched out to one set of four in four hours, for each operator.

Process Control with Parallel Units

STUDY ON DIAL-FEED MACHINE.—The preceding paragraphs did not refer to the case of systematic differences between parallel machines, and their effects upon variability in the common product. The following illustration deals with this case, where the parallel units are heads on a dial-feed type of machine.

Glass buttons were formed with 7 pin-lead inserts for bases of a small device. The machine had 16 heads, each with lower and upper elements. Seven leads were inserted by hand into well pockets in the lower element and a glass bead of specified size and weight was placed in the center. Each head indexed around the machine through heating, forming, and annealing stages. Fig. 12 illustrates the cross section, with the dimension here discussed. The exposed pin length was uncontrolled in the common flow of parts to inspection, with a substantial fraction outside specification limits.

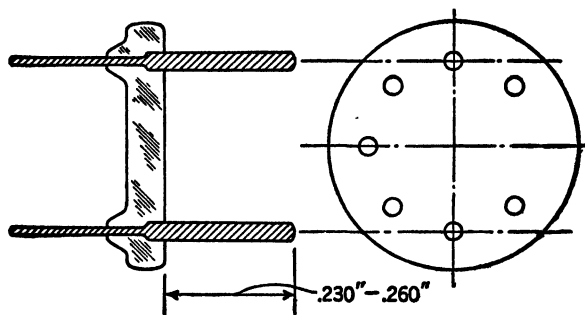



Fig. 12. Base for Device, Assembled from Pin Inserts and Glass Button

Causes of Variations.—Possible assignable causes were: improper placing of leads in well pockets due to carelessness or to fouling of the pockets; adjustment of well-pocket depths; improper maintenance of cams and rollers operating the head movements, etc. Since assignable differences were suspected to exist between heads, and between each head and specification bogey, one button (here considered as a sample of 7 leads) was taken from each head, each hour.

Control charts were made up for means of 7 leads, for each head. A typical data sheet is shown in Fig. 13. The mean range was computed over a representative historical period for each head. Control charts for means and ranges were posted on the operating floor.

(Values in Thousandths of One Inch)

Head	Pin Numbers							Mean $\overline{X}$	Range R	Remarks
	1	2	3	4	5	6	7			
1	246	252	252	249	252	249	238	248	14	
2	255	263	265	264	265	265	258	262	10	
3	251	253	251	247	248	247	250	249	6	(1)
4	235	222	246	246	238	250	240	239	28	
5	256	265	261	262	264	261	257	261	9	
6	241	239	240	242	246	248	234	241	14	(2)
7	257	260	260	257	258	255	255	257	5	
8	258	263	260	261	259	260	257	259	4	
9	264	260	265	260	254	256	259	259	11	
10	243	250	245	252	250	239	243	246	8	
11	251	253	254	255	255	251	247	252	8	
12	240	244	234	238	244	247	248	242	14	(3)
13	250	253	252	254	255	252	247	252	8	
14	237	236	236	230	236	238	233	235	8	(4)
15	248	251	254	253	253	255	255	253	7	
16	256	256	258	258	258	257	255	254	3	(3)
Total.....								4,009	157	
Average...								250.6	9.8	

(1) Fouling reported by operator.
(2) Head height recently adjusted.
(3) Recurrent trouble with cam mechanism on this head.
(4) Recently adjusted.

Fig. 13. Typical Data Sheet for Control Inspection of Exposed Pin Lengths

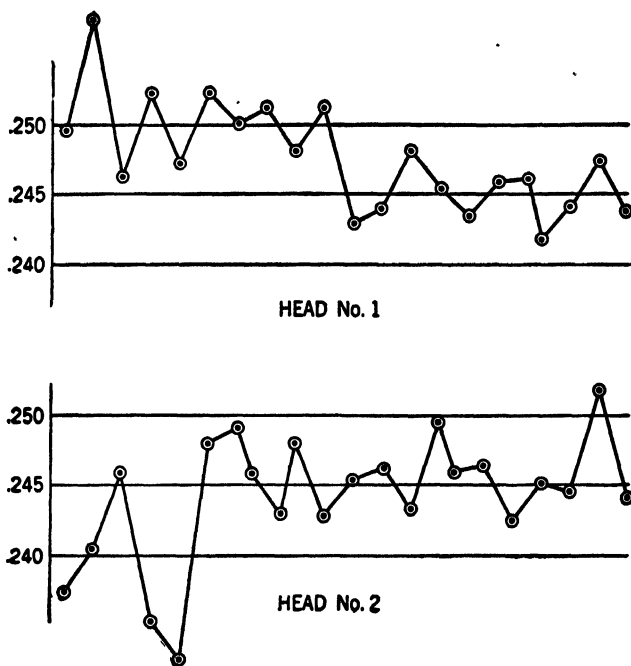



FIG. 14. Control Charts for Study of Heads on Dial-Feed Machine, for Exposed Pin Length Means

Fig. 14 illustrates the charts for means for a few of the heads. It was soon apparent to the maintenance men that some heads were averaging high, others low. Successive approximations of adjustment quickly brought the heads to average on bogey. In addition, the charts provided prompt indications of the entrance of occasional assignable causes such as glass particles and fouling in well pockets. The charts for ranges not only indicated such failure in individual pockets, but through improper levels (average range, $\bar{R}$) showed which heads needed cleaning and equalization of the pocket depths by the toolmakers.

Improvements Brought About.—In a relatively short period, the control of exposed pin length was improved to a point where extremely few pins were outside limits; and it was planned to drop 100% acceptance inspection in favor of patrol sampling inspection when the stability of control was established.

Control charts were continued for supervision, upon the insistence of the production maintenance department.

Set-Up and Patrol Inspection for Control

INITIAL QUESTIONS.—In considering statistical control methods for the first time, several challenging questions appear repeatedly. Does not conventional patrol inspection provide all of the control necessary? Are not control chart requirements uneconomic with short production runs? Is it not impossible to maintain analytical methods and charts on a product with a great number of critical dimensions, as found with some punch press operations?

First, it has been stressed above that these methods compose merely a systematic and quantitative way of thinking about variability, about cause and effect; and the effort expended in a particular case should be in proportion to unit cost and required precision.

The short-run and patrol inspection questions are closely related. Experience has demonstrated that the essential weaknesses of patrol supervision are insufficient measurement and unsystematic uses of information. First comes the problem of proper set-up, then that of efficient and systematic patrol inspection. Because of the inherent variability of any process, "first piece" inspection should be performed on a sample in most cases. The set-up should locate the spread of values with respect to the center of the specification limits or in a manner using economically any interval available for tool-wear drift, while giving reliable assurance that the specification limits will not be violated. After set-up and tooling have proved satisfactory, patrol inspection must provide reliable checks upon the maintenance of satisfactory conditions with control samples. Again, allowance must be made for chance variability, taking action only when such allowance is exceeded.

APPLICATION OF CONTROL CHARTS.—In many industrial processes the control chart is given in different form, now being provided with an extension of the same principle using **acceptance lines** inside of, and referenced to, the specification limits. The acceptance lines provide a criterion of safe range for patrol sample means, i.e., the appearance of means outside these lines indicates danger that the current process average has deteriorated to a point where a serious proportion of the chance variability may be outside specification limits. It would then be hazardous to accept the material produced since the last sample, at least without further investigation.

In cases where appreciable tool wear—as an assignable cause—must be left in the process for economic reasons, a normal trend pattern is apparent, and the conventional control limits become less useful unless they can be set up around a reasonably reliable trend line in place of constant central line. In such cases they are sometimes omitted, relying upon judgment of the conformance of the developed pattern to the expected trend.

Chart Analysis.—In Fig. 15 are illustrated two cases of the extended chart. The first, in (a), is a case where acceptance lines appear outside the control limits. In (b), the former are inside the control limits because of the tightness of the specification limit tolerance with respect to an undesirably large characteristic variability in the process. The latter event indicates that the inherent chance variability of the process is too large and that process redesign may be in order.

For practical purposes, the acceptance lines are located inside the specification limits at a distance of 3 standard deviations, σ'. The σ' can be approximated by $\hat{\sigma} = \bar{\sigma}/c_2$ or $\hat{\sigma} = \bar{R}/d_2$ as indicated in the discussion of Fig. 11.

Of initial importance, however, is the need to record and interpret findings in a systematic way. It should be noted that **patrol** inspection is **control** inspection, when done systematically. The gain in information and control is of utmost economic significance. A useful discussion of this technique can be found in A First Guide to Quality Control for Engineers, Ministry of Supply, London.

INDICATOR QUALITIES.—Where there are many critical characteristics on a part, many situations permit selection of a few "indicator" qualities for control supervision after approval of the set-up. These "indicators" will usually reflect the presence of the major assignable causes tending to influence all characteristics; e.g., in punch press operation, such causes as die failure, poor machine adjustment, defective strip stock, etc.

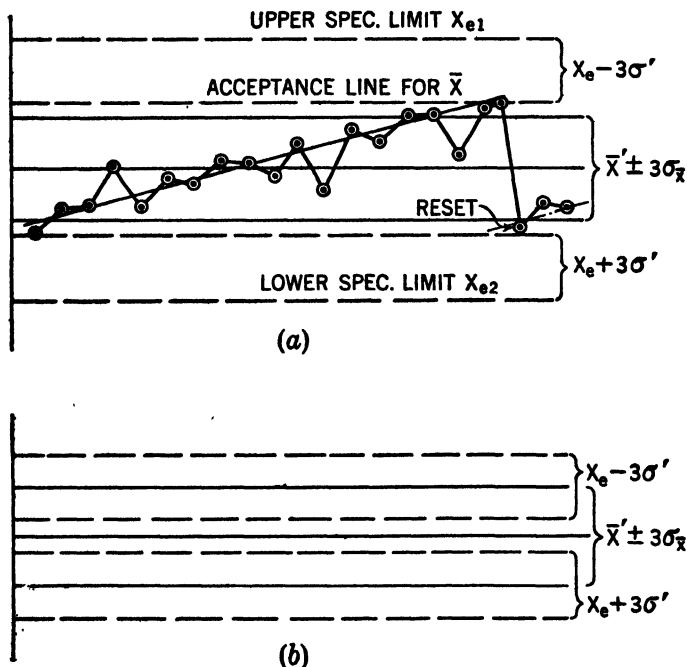



FIG. 15. Control Charts Using Acceptance Lines Referenced to the Specification Limits

Application to Molded Part.—The following discussion by Manuele suggests useful approaches to these problems. (Joseph Manuele, Quality Control, The Tech Engineering News, vol. 25.)

"A good application of statistical analysis is the molded part shown in Fig. 16. This part is made in a 16-cavity mold and considerable difficulty was being experienced in maintaining the .245 ± .003 in. dimension. Therefore, the first step was to determine whether the part could be made.

"Thirty-three pieces were taken from each cavity and carefully measured. From these measurements the average, $\overline{X}$, of the pieces produced by each cavity was calculated. The standard deviation, σ, was also calculated. These two statistics, for 8 cavities, are shown in Fig. 17. (The entire tables are not shown, in order to conserve space.)

"Remembering that according to the normal curve 99.7% of the parts will be produced within the limits $\overline{X} \pm 3\sigma$, we find that the parts are being produced within the proper tolerances (3σ is smaller than .003 in. for each of the cavities), but $\overline{X}$ is too far from the drawing nominal dimension (.245 in.) in every cavity. This means that the part can be made within the tolerances required, but the individual mold cavities must be adjusted to bring the average of each cavity to .245 in.; cavity No. 1 will have to be closed .0021 in., cavity No. 2 will have to be closed .0085 in., and so on.

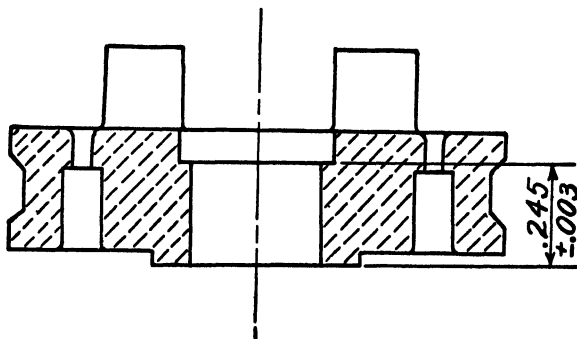



Fig. 16. Molded Part to Which Statistical Quality Control Analysis Was Applied

"Fig. 18 shows the average and standard deviation for 50 pieces produced in each of 8 cavities after the mold was corrected. This shows that the operation should produce parts which are all satisfactory. A detail inspection of 1,000 parts revealed no rejections; an inspection of 10% of a subsequent lot of 6,000 parts also failed to reveal any defective units.

Corrections in Condition.—"As a result of this investigation and mold correction, a counterboring operation was eliminated, thus materially reducing the cost of the part; the detail inspection of all parts was also

	No. 1	No. 2	No. 3	No. 4
$\bar{\bar{X}}$	.2471	.2535	.2579	.2573
σ	.0009	.0009	.0010	.0006
3σ	.0027	.0027	.0030	.0018
	No. 5	**No. 6**	**No. 7**	**No. 8**
$\bar{\bar{X}}$	.2559	.2599	.2576	.2542
σ	.0008	.0007	.0005	.0006
3σ	.0024	.0021	.0015	.0018

FIG. 17. The Average and Standard Deviation of 33 Parts (Fig. 16) Produced in Each Cavity Before Correction to Mold

	No. 1	No. 2	No. 3	No. 4
$\bar{\bar{X}}$	.2444	.2446	.2442	.2460
σ	.0006	.0005	.0009	.0009
3σ	.0018	.0015	.0027	.0027
	No. 5	**No. 6**	**No. 7**	**No. 8**
$\bar{\bar{X}}$	.2454	.2461	.2444	.2442
σ	.0008	.0008	.0009	.0007
3σ	.0024	.0024	.0027	.0021

FIG. 18. The Average and Standard Deviation of 50 Parts (Fig. 16) Produced in Each Cavity After Correction to Mold

eliminated, thus materially reducing the cost of inspection; also the full productive capacity of the operation is now being utilized as all parts produced are acceptable. From this point on, only an occasional floor inspection, to guard against mold wear, is required to insure the continued production of satisfactory parts.

"The control chart technique differs very little from the statistical analysis method. The original inspection and calculations are the same. Fig. 19 shows a typical part to which the control chart technique has been applied. Fig. 20 shows a small cross section from the production history of this part. It will be noted that an average of 22.3% of the parts inspected during this period were rejected. Another striking fact is the variation in the percentage of defective parts produced from day to day.

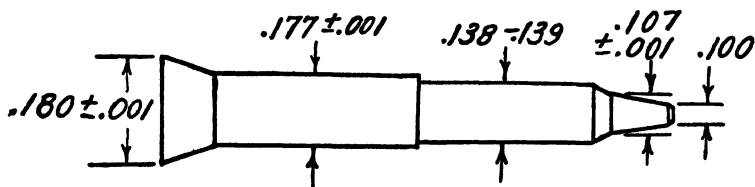



FIG. 19. Typical Part to Which Quality Control Technique Was Applied

History of Part Before Application
of Statistical Control

Date	Number Inspected	Number Rejected	Per Cent Defective
7/18	1,240	97	7.8
7/18	1,240	381	30.7
7/20	1,144	194	17.0
7/28	1,478	198	13.4
7/28	1,130	370	32.3
7/28	1,549	919	59.3
7/31	1,457	257	17.6
7/31	2,090	450	21.5
7/31	1,193	83	6.9
8/2	2,200	630	28.6
8/2	1,850	322	17.4
8/3	2,150	300	14.0
8/3	1,860	392	21.1
8/4	1,327	287	21.6
Total.........	21,908	4,880	22.3

Fig. 20. Variation of the Percentage of Defective Parts (Fig. 19) Produced Day by Day

"Fig. 21 shows the work sheets used in establishing statistical control over this item. A sample of 25 pieces was taken and each of the four critical dimensions was measured. From the measurements, the average $\bar{X}$ and the standard deviation σ for each dimension were calculated. The machine set-up was adjusted and the cutting tools were dressed until $\bar{X}$ was very close to the nominal drawing dimension, and three times the standard deviation (3σ) was less than one-half the drawing tolerance.

Quality Control Under Small Tolerances.—"Fig. 22 shows a typical control chart used for controlling the quality of parts which must be made to small tolerances. The chart is also a complete log of what was done to the machine and the tools during the running of the job. The chart shows that a good machine set-up will run for 15 to 20 hr. continuously without requiring any adjustments, or dressing of tools. It is long runs like that shown on this chart that reduce unit costs, increase production, and produce good quality parts which require no inspection later.

"Fig. 23 shows the history of the production of four successive days, three days when the control chart was used and one day when the control chart was not used. It might be argued that the period covered is not long enough to provide us with conclusive evidence. These are short runs; some orders are even shorter. But the pattern of the history is always the same, proving conclusively the value of the control chart for controlling quality.

Need for Training in Methods.—"Statistical methods require that the person using them have some training in these methods; they also require an understanding and sympathetic attitude on the part of the production organization, 'the shop people.' It is a fact that the initial inspection and calculations to determine the average $\bar{X}$ and the standard

TEST RECORD
WESTINGHOUSE FORM 2309 D BODY

THE SPACE ABOVE THIS LINE IS FOR FILING AND MUST NOT BE WRITTEN ON B 51691

SUBJECT RIVET
CUSTOMER ___ SERIAL NO ___
S O OR TEST NO ___ D OR L SPEC NO ___ SHAFT NO ___ FRAME NO ___
TO DETERMINE ___

(A)		f	10^{-4} DEV	$DEV^2 \times 10^{-8}$	(f)DEV^2
.1797	/	1	4	16	16
.1798	/	1	3	9	9
.1799	////	4	2	4	16
.1800	HH /	6	1	1	6
.1801	HH	5	0	0	0
.1802	HH	5	1	1	5
.1803	//	2	2	4	8
.1804			3	9	0
.1805	/	1	4	16	16

$\bar{X}$ = .1801 AVE DEV² = 3 × 10^{-8}
σ = .00017
3σ = .0005

(B)		f	10^{-4} DEV	10^{-8} DEV^2	(f)D^2
.1769	/	1	3	9	9
.1770	///	3	2	4	12
.1771	HH	5	1	1	5
.1772	HH HH /	11	0	0	0
.1773	///	3	1	1	3
.1774	//	2	2	4	8

$\bar{X}$ = .1772 AVE DEV = 1.5 × 10^{-8}
σ = $\sqrt{.000000015}$
= .00012
3σ = .00036
OR .0004

(C)		f	D 10^{-4}	D^2 10^{-8}	fD^2
.1383	/	1	2	4	4
.1384	////	4	1	1	4
.1385	HH HH HH	15	0	0	0
.1386	HH	5	1	1	5

$\bar{X}$ = .1385 AVE DEV² = .36 × 10^{-8}
σ = .00006
3σ = .0002

(D)		f	D 10^{-4}	D^2 10^{-8}	fD^2
.1068	/	1	3	9	9
.1069	///	3	2	4	12
.1070	HH	5	1	1	5
.1071	HH HH	10	0	0	0
.1072	HH	5	1	1	5
.1073	/	1	2	4	4

$\bar{X}$ = .1071 AVE DEV² = 1.5 × 10^{-8}
σ = .00012
3σ = .0004

DRG. LIMITS
(A)
.1790 .1800 .1810

PREVIOUS TEST PAGE ___ DATE ___ SIGNED ___ ENGINEER IN CHARGE ___

Fig. 21. Work Sheet Used in Making the Study on the Part in Fig. 19

deviation σ require an appreciable time, and sometimes it is difficult to explain to 'the shop people' that this work is necessary. To overcome these objections, a system of 'first piece + patrol + last piece' inspection has been developed which can control quality so that the production of defective parts is practically eliminated. This method is particularly adaptable to punch press operations, welding and brazing operations, grinding operations, and fixture assembly operations where several parts are assembled and riveted in a machine. This method also has been used on automatic and semi-automatic screw machines, turret lathes, and when grinding journals on shafts. This method requires no training beyond that possessed by the inspector who is to inspect the work."

Acceptance Sampling Inspection Plans

LOT SAMPLING INSPECTION.—Lot sampling inspection for purposes of acceptance, rejection, or other action upon specific lots of material has been a tempting alternative for 100% screening inspection for some time. Such inspection problems arise in two forms: (1) on single lots or consignments with little or no history of process performance; (2) on a continuous sequence of lots or shipments from the same source where historical information has been built up. Unfortunately, many manufacturers have attempted plans arrived at intuitively and arbitrarily, with resulting losses from large fractions of defectives reaching operating departments and ultimate consumers.

The essence of any sampling plan is the reliability with which the sample presents a picture of the collective quality of the lot upon which action is taken. Any rational plan design depends upon such factors as size of sample, size of lot, tolerated fractions defective, degree of control of the process producing the lot, cost of inspection, cost created by defective material getting through inspection, etc.

Since the units composing a particular sample, and therefore the relationship between sample quality and lot quality, depends upon chance, the laws of probability must be recognized in inferences from sample to lot.

In general, when the recipient of a product, or a manufacturer inspecting for a recipient's protection, adopts a sampling inspection plan in place of 100% screening, he gives up his assurance that **every piece** released conforms to specifications. The design of a plan requires the choice of some maximum allowable per cent defective, applied either to each lot inspected or to the average flow of product lots in a more or less continuous sequence.

INSPECTION BY METHOD OF ATTRIBUTES.—The most general type of inspection in industry is that known as the method of attributes, i.e., each piece is inspected on a go, not-go basis. Discussion is here confined to sampling inspection for this type.

Since sampling plan designs must recognize chance variability in judging a lot, allowable risks of error in judgment must first be established. Applications of the theory of probability to the design of rational sampling plans require the training of a specialist. It is impossible to discuss here even the basic mathematical reasoning employed,

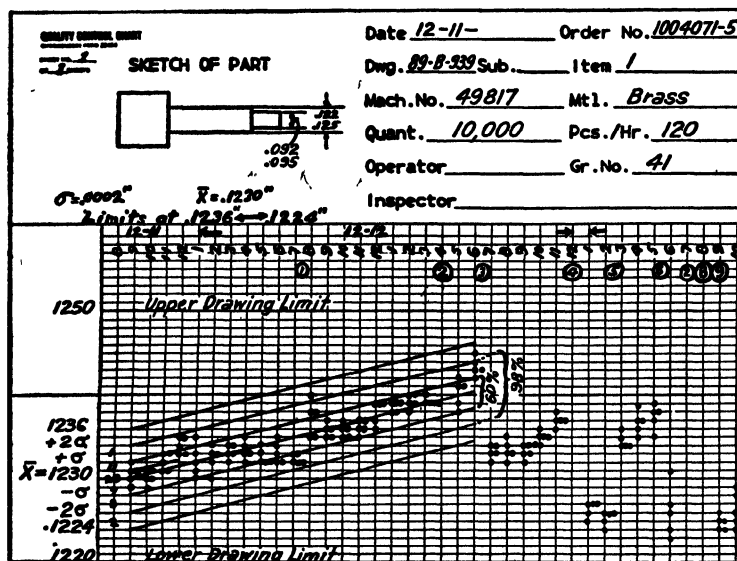
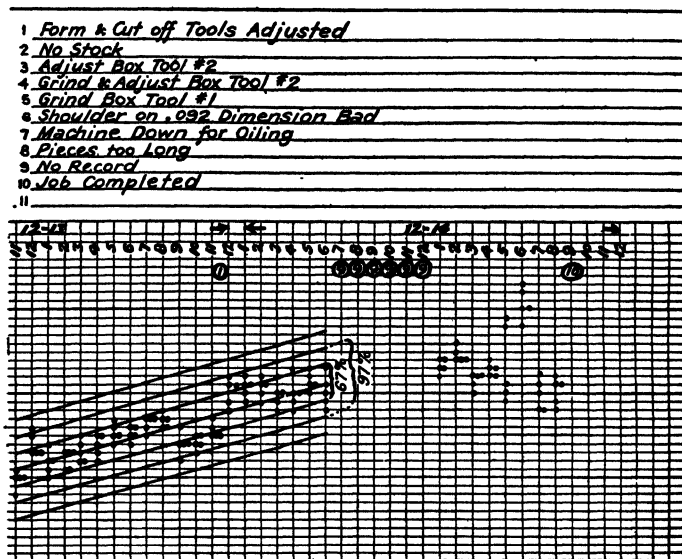



Fig. 22. Control Chart Used for Controlling

Fortunately, some plans have been designed, tried, and published in forms permitting general use under the conditions prescribed.

Practical Plans.—Best known and most generally applicable are those developed for use in the Western Electric Co. (Dodge and Romig, Single Sampling and Double Sampling Inspection Tables, Bell System Tech. Jl., vol. 20; also Monog. B-1274, Bell. Tel. System Tech. Publication). These were developed for use in consumer and producer inspections of products composed of similar pieces. Maximum advantage from their use is obtained with nondestructive testing, with more or less continuously produced products rather than those produced intermittently on a small scale.

Two Kinds of Protection.—Two kinds of protection are used. Tables for **lot quality protection** prescribe some chosen value of allowable fraction defective in a lot, known as lot tolerance fraction, p_t; also a selected probability or **consumer risk** of accepting a lot of just the lot tolerance fraction defective. (The risk is less for accepting a lot of worse quality.) The consumer risk in the Western Electric tables is 10%. Tables for average outgoing quality protection are based upon a selected maximum value of average fraction defective in the flow of product after inspection, known as **average outgoing quality limit** (AOQL), that will not be exceeded no matter what fraction defective is submitted to inspection.

Quality of Parts Made to Small Tolerances

History of Part After Control Chart Was Established

Date	Number Inspected	Number Rejected	Per Cent Rejected	Control Chart Used
5/2	1,120	2	.2	Yes
5/3	950	3	.3	Yes
5/4	840	17	2.0	Yes
5/5	850	117	14.0	No

Fig. 23. Results Obtained With and Without the Use of the Control Chart (Fig. 22)

The lot quality protection tables are usually applied to cases where lots retain their identity after inspection, in that a lot may be shipped as inspected to a consumer in a specific transaction. Tables for average quality protection are used where lots are merged in a common supply where average performance is of interest, as in subsequent operations within the same jurisdiction, or in cases of continual deliveries on large quantity commitments.

For each type of protection the plans are designed to provide the minimum amount of inspection when lots of material have the process average fraction defective $\bar{p}$, subject to the consumer risk mentioned above. With the further assumption that those lots whose samples fail

Process Average %	0–.03			.04–.30			.31–.60			.61–.90			.91–1.20			1.21–1.50		
Lot Size	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %
1–40	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0
41–55	40	0	.18	40	0	.18	40	0	.18	40	0	.18	40	0	.18	40	0	.18
56–100	55	0	.30	55	0	.30	55	0	.30	55	0	.30	55	0	.30	55	0	.30
101–200	65	0	.38	65	0	.38	65	0	.38	65	0	.38	65	0	.38	65	0	.38
201–300	70	0	.40	70	0	.40	70	0	.40	110	1	.48	110	1	.48	110	1	.48
301–400	70	0	.43	70	0	.43	115	1	.52	115	1	.52	115	1	.52	155	2	.54
401–500	70	0	.45	70	0	.45	120	1	.53	120	1	.53	160	2	.58	160	2	.58
501–600	75	0	.43	75	0	.43	120	1	.56	160	2	.63	160	2	.63	200	3	.65
601–800	75	0	.44	125	1	.57	125	1	.57	165	2	.66	205	3	.71	240	4	.74
801–1,000	75	0	.45	125	1	.59	170	2	.67	210	3	.73	250	4	.76	290	5	.78
1,001–2,000	75	0	.47	130	1	.60	175	2	.72	260	4	.85	300	5	.90	380	7	.95
2,001–3,000	75	0	.48	130	1	.62	220	3	.82	300	5	.95	385	7	1.0	460	9	1.1
3,001–4,000	130	1	.63	175	2	.75	220	3	.84	305	5	.96	425	8	1.1	540	11	1.2
4,001–5,000	130	1	.63	175	2	.76	260	4	.91	345	6	1.0	465	9	1.1	620	13	1.2
5,001–7,000	130	1	.63	175	2	.76	265	4	.92	390	7	1.1	505	10	1.2	700	15	1.3
7,001–10,000	130	1	.64	175	2	.77	265	4	.93	390	7	1.1	550	11	1.2	775	17	1.4
10,001–20,000	130	1	.64	175	2	.78	305	5	1.0	430	8	1.2	630	13	1.3	900	20	1.5
20,001–50,000	130	1	.65	225	3	.86	350	6	1.1	520	10	1.2	750	16	1.4	1,090	25	1.6
50,001–100,000	130	1	.65	265	4	.96	390	7	1.1	590	12	1.3	830	18	1.5	1,215	28	1.6

n = Size of sample; entry of "All" indicates that each piece in lot is to be inspected
c = Allowable defect number for sample
AOQL = Average outgoing quality limit

FIG. 24. Single Sampling (Lot tolerance per cent defective = 3%).

to meet the acceptance criterion have their remainders detail inspected, the **long-run** amount of inspection per lot is made of two parts. The acceptance criterion in the tables is a stated number of allowable defective units in a given sample size, designated c, in a sample of size n from a lot of size N. One part is the number of pieces in the required sample from each lot. The other part is the average number of pieces inspected per lot as a result of the failure of some lots to meet the sample acceptance criterion.

Single Sampling and Double Sampling.—For each type of protection, two methods are provided: single sampling and double sampling. These methods are distinguished by the number of samples that may be taken before a decision is reached regarding proper action on the lot. The procedures on each case are outlined in the following quotation (Dodge and Romig, as above cited):

Single Sampling Inspection Procedure:

a. Inspect a sample of n pieces.
b. If the number of defects found in the sample does not exceed c, accept the lot.
c. If the number of defects found in the sample exceeds c, inspect all the pieces in the remainder of the lot.
d. Correct or replace all defective pieces found.

Double Sampling Inspection Procedure:

a. Inspect a first sample of n_1 pieces.
b. If the number of defects found in the first sample does not exceed c_1, accept the lot.
c. If the number of defects found in the first sample exceeds c_2, inspect all the pieces in the remainder of the lot.
d. If the number of defects found in the first sample exceeds c_1 but does not exceed c_2, inspect a second sample of n_2 pieces.
e. If the total number of defects found in the first and second samples combined does not exceed c_2, accept the lot.
f. If the total number of defects found in the first and second samples combined exceeds c_2, inspect all the pieces in the remainder of the lot.
g. Correct or replace all defective pieces found.

Generally, double sampling provides a lower average amount of inspection than single sampling in the long run. However, there are other considerations of cost which may offset this advantage, such as interruptions in work flow when a second sample is required, extra handling, more difficulty in explaining the operation of the method, etc.

Sampling Method Data.—Fig. 24 illustrates a single sampling lot tolerance for lot tolerance 3%. Fig. 25 illustrates a double sampling AOQL table, for AOQL of 10%. (Dodge and Romig.)

In a specific consideration of replacement of 100% inspection by sampling inspection, the first step is the determination whether or not the quality is good enough, principally in the sense of a process average defective $\bar{p}$ that can reasonably be predicted to hold in the future. The columns in each table, for the various process averages, are those in the range where sampling can advantageously be employed. It should be noted in practice that these plans induce consideration of better process control, since the attainment of lower process average fraction defective

Process Average %	0–.20						.21–2.00						2.01–4.00					
	Trial 1		Trial 2			p_t %	Trial 1		Trial 2			p_t %	Trial 1		Trial 2			p_t %
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–3	All	0	–	–	–	–	All	0	–	–	–	–	All	0	–	–	–	–
4–15	3	0	–	–	–	50.0	3	0	–	–	–	50.0	3	0	–	–	–	50.0
16–50	5	0	3	8	1	53.5	5	0	3	8	1	53.5	5	0	3	8	1	53.5
51–100	5	0	3	8	1	55.0	6	0	8	14	2	43.0	6	0	8	14	2	43.0
101–200	5	0	4	9	1	52.0	7	0	7	14	2	42.0	7	0	12	19	3	38.0
201–300	7	0	7	14	2	42.5	7	0	7	14	2	42.5	7	0	13	20	3	37.0
301–400	7	0	7	14	2	42.5	7	0	7	14	2	42.5	8	0	17	25	4	35.0
401–500	7	0	8	15	2	40.0	7	0	8	15	2	40.0	8	0	18	26	4	34.0
501–600	7	0	8	15	2	40.0	8	0	13	21	3	35.0	8	0	18	26	4	34.0
601–800	7	0	8	15	2	40.5	8	0	13	21	3	35.0	8	0	18	26	4	34.5
801–1,000	7	0	8	15	2	40.5	8	0	13	21	3	35.0	9	0	18	27	4	33.0
1,001–2,000	7	0	8	15	2	40.5	8	0	14	22	3	34.0	9	0	23	32	5	31.0
2,001–3,000	7	0	8	15	2	41.0	8	0	14	22	3	34.0	9	0	24	33	5	30.0
3,001–4,000	7	0	8	15	2	41.0	8	0	14	22	3	34.5	9	0	24	33	5	30.5
4,001–5,000	7	0	8	15	2	41.0	8	0	14	22	3	35.0	10	0	29	39	6	29.5
5,001–7,000	7	0	8	15	2	41.0	9	0	18	27	4	32.5	16	1	29	45	7	28.5
7,001–10,000	7	0	8	15	2	41.0	9	0	18	27	4	32.5	17	1	38	55	8	26.0
10,001–20,000	7	0	8	15	2	41.0	9	0	18	27	4	32.5	17	1	38	55	8	26.0
20,001–50,000	7	0	8	15	2	41.0	9	0	18	27	4	32.5	18	1	42	60	9	25.5
50,001–100,000	8	0	14	22	3	33.5	9	0	25	34	5	30.0	18	1	52	70	10	24.5

n_1 = Size of first sample
n_2 = Size of second sample
Entry of "All" indicates that each piece in lot is to be inspected.
The second column under Trial 2 in each case equals $n_1 + n_2$.

FIG. 25. Double Sampling (Average

for the same order of protection (lot tolerance % or AOQL%) will permit alternatively smaller amounts of sampling.

OTHER SAMPLING INSPECTION PROBLEMS.—There are many other sampling conditions for which there are not yet general solutions, and which require specialized treatment in specific cases.

First above is the case of a single consignment, where there is little if any historical background regarding the manufacturing conditions (L. E. Simon, An Engineers' Manual of Statistical Methods).

There is also the case of destructive testing, where obviously the lot remainders cannot be detailed. The Dodge-Romig tables are based upon minimum average inspection effort, with lot remainder detailing. Although tables can be calculated for the destructive test, cost considerations (as loss by destruction) play such an important part that generalizations are difficult to make. In many cases acceptance action for a product can be approached by attaining control at acceptable levels by means of control chart procedures.

In some cases conditions warrant the use of acceptance **sampling inspection by the method of variables** or measurements. Unfortunately,

4.01–6.00						6.01–8.00						8.01–10.00					
Trial 1		Trial 2			p_t %	Trial 1		Trial 2			p_t %	Trial 1		Trial 2			p_t %
n_1	c_1	n_2	$n_1 + n_2$	c_2		n_1	c_1	n_2	$n_1 + n_2$	c_2		n_1	c_1	n_2	$n_1 + n_2$	c_2	
All	0	–	–	–	–	All	0	–	–	–	–	All	0	–	–	–	–
3	0	–	–	–	50.0	3	0	–	–	–	50.0	3	0	–	–	–	50.0
6	0	6	12	2	48.0	6	0	6	12	2	48.0	6	0	6	12	2	48.0
7	0	11	18	3	38.5	7	0	11	18	3	38.5	7	0	16	23	4	36.5
8	0	16	24	4	35.5	13	1	20	33	6	33.5	14	1	24	38	7	32.0
8	0	17	25	4	35.0	14	1	26	40	7	31.5	19	2	29	48	9	31.0
8	0	22	30	5	34.0	15	1	30	45	8	31.0	21	2	44	65	12	29.0
15	1	23	38	6	30.5	16	1	39	55	9	28.5	22	2	53	75	13	27.0
16	1	28	44	7	28.5	22	2	38	60	10	27.5	28	3	52	80	14	26.5
16	1	28	44	7	29.0	22	2	43	65	11	27.0	29	3	56	85	15	26.0
16	1	34	50	8	28.0	24	2	56	80	13	25.5	36	4	69	105	18	24.5
17	1	38	55	9	27.5	24	2	61	85	14	25.0	45	5	95	140	23	23.0
17	1	48	65	10	26.0	33	3	72	105	16	23.0	50	6	115	165	27	22.0
24	2	46	70	11	25.0	41	4	99	140	21	21.5	70	8	150	220	34	20.5
26	2	54	80	12	23.5	44	4	111	155	22	20.0	80	9	195	275	41	19.0
27	2	63	90	13	22.5	50	5	120	170	24	19.5	90	10	240	330	47	18.0
27	2	68	95	14	22.0	60	6	145	205	28	18.5	110	12	265	375	53	17.5
28	2	77	105	15	22.0	70	7	165	235	32	18.0	125	14	320	445	62	17.0
28	2	87	115	17	21.5	80	8	205	285	39	17.5	140	16	355	495	69	16.8
36	3	99	135	20	21.0	85	8	245	330	44	17.0	150	17	390	540	77	16.6

c_1 = Allowable defect number for first sample
c_2 = Allowable defect number for first and second samples combined
p_t = Lot tolerance per cent defective corresponding to a consumer's risk (p_c) = .10

output quality limit = 10%).

it is required that a good degree of control be first obtained, and that the designer be competent in the theory of statistics.

U. S. ARMY ORDNANCE TABLES.—In recent years a specialized sampling plan has been devised for the use of U. S. Army Ordnance inspectors. This was to serve in the **check** inspection of work already passed by a vendor manufacturer's final inspection. Minor revisions and extensions of these tables have been made since their first publication. Figs. 26 and 27 indicate the form of these tables (Gause, Quality Through Inspection, U. S. Army Ordnance, vol. 25).

The tables call for a double sampling procedure. The acceptance numbers are determined for three conditions: (1) the sample size; (2) the class of defects, i.e., major or minor; and (3) the acceptable quality level, or acceptable process average fraction defective. The emphasis is upon the **average** fraction defective which the manufacturer can be allowed to present continually for acceptance, with acceptance numbers selected so that lots of the acceptable average fraction defective will be accepted roughly 95% of the time.

Sublot Size		500–799		800–1,299		1,300–3,199		3,200–7,999		8,000–21,999		22,000–109,999		110,000 and over		Maximum A.O.Q.L. (Per cent defective)
First Sample Size		50		75		100		150		200		300		500		
Second Sample Size		100		150		200		300		400		600		1,000		
Acceptable Quality Level (Per cent defective)		Acceptance Numbers		Acceptance Numbers		Acceptance Numbers		Acceptance Numbers		Acceptance Numbers		Acceptance Numbers		Acceptance Numbers		
Major	*Minor*	c_1	c_2	c_1	c_2	c_1	c_2	c_1	c_2	c_1	c_2	c_1	c_2	c_1	c_2	
.010–.020	....	*	*	*	*	*	*	*	*	*	*	*	*	0	1	.08
.021–.030	.010–.020	*	*	*	*	*	*	*	*	*	*	0	1	0	2	.15
.031–.060	.021–.030	*	*	*	*	*	*	*	*	0	1	0	2	1	3	.20
.061–.10	.031–.060	*	*	*	*	*	*	0	1	0	2	1	2	1	4	.30
.11–.15	.061–.10	*	*	*	*	0	1	0	2	0	3	1	3	2	5	.40
.16–.25	.11–.15	*	*	0	1	0	2	1	3	1	4	2	5	3	7	.60
.26–.50	.16–.25	0	2	1	2	1	3	2	4	2	7	3	8	4	13	1.0
.51–1.0	.26–.50	1	3	2	4	2	6	3	9	4	11	5	13	7	23	1.7
1.1–2.0	.51–1.0	2	4	3	5	3	8	5	13	6	16	8	25	14	40	2.7
2.1–3.0	1.1–2.0	3	5	4	8	5	11	7	18	9	24	12	35	†	†	3.7
3.1–4.0	2.1–3.0	3	9	5	11	6	16	9	23	11	32	16	47	†	†	4.2
4.1–5.0	3.1–4.0	4	10	6	14	8	19	11	28	14	37	†	†	†	†	5.3
....	4.1–5.0	5	12	7	17	10	23	14	33	18	44	†	†	†	†	6.5

*Table not applicable in this region. †Use sample size in first columns to left in which acceptance numbers are shown for acceptable-quality level involved.

TABLE I

Procedure for Major Defects.—(1) Select first sample of size indicated in Table I for sublot size involved; (2) Determine in first sample the number of articles, d_1, which contain major defects. (*a*) If d_1 does not exceed the c_1 indicated for the acceptable-quality level (major) involved, pass the sublot for majors; (*b*) If d_1 exceeds the corresponding c_2, reject the sublot, (*c*) If d_1 exceeds c_1 but does not exceed c_2, select a second sample of the size indicated in Table I and determine in this second sample the number of articles, d_2, which contain major defects. If $d_1 + d_2$ does not exceed c_2, pass the sublot; if $d_1 + d_2$ exceeds c_2, reject the sublot.

For Minor Defects.—Carry out above procedure with "minor" substituted everywhere for "major," using same sample wherever feasible.

Disposition of Sublot.—If passed for both major and minor defects by above procedure, accept as conforming; if rejected for either major or minor defects by above procedure, return to contractor.

Notes.—Reject all defective articles observed in any of the above inspections. A.O.Q.L. values in right-hand column are poorest average quality accepted if all rejected lots are inspected one hundred per cent and accepted after removal of all defective articles. Above procedure is satisfactory when process average is equal to or better than acceptable-quality level. If process average is poorer than this, acceptance numbers that correspond with the A.O.Q.L. value which is equal to or next better than the acceptable-quality level should be used.

Fig. 26. Normal Lot-by-Lot Acceptance Inspection: Double Sampling

Sublot Size		500–799			800–1,299			1,300–3,199			3,200–7,999			8,000–21,999			22,000–109,999			110,000 and over		
First Sample Size		10			15			20			30			40			60			100		
Second Sample Size		140			210			280			420			560			840			1,400		
Acceptable Quality Level (Per cent defective)		Acceptance Numbers			Acceptance Numbers			Acceptance Numbers			Acceptance Numbers			Acceptance Numbers			Acceptance Numbers			Acceptance Numbers		
Major	*Minor*	c_1	c_2	c_e	c_1	c_2	c_e	c_1	c_2	c_e	c_1	c_2	c_e	c_1	c_2	c_e	c_1	c_2	c_e	c_1	c_2	c_e
.010–.020	....	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	1	0
.021–.030	.010–.020	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	1	0	0	2	0
.031–.060	.021–.030	*	*	*	*	*	*	*	*	*	*	*	*	0	1	0	0	2	0	0	3	1
.061–.10	.031–.060	*	*	*	*	*	*	*	*	*	0	1	0	0	2	0	0	2	1	0	4	1
.11–.15	.061–.10	*	*	*	*	*	*	0	1	0	0	2	0	0	3	0	0	3	1	1	5	2
.16–.25	.11–.15	*	*	*	0	1	0	0	2	0	0	3	1	0	4	1	1	5	2	1	7	3
.26–.50	.16–.25	0	2	0	0	2	1	0	3	1	1	4	2	1	7	2	1	8	3	1	13	4
.51–1.0	.26–.50	0	3	1	1	4	2	1	6	2	1	9	3	1	11	4	2	13	5	2	23	7
1.1–2.0	.51–1.0	1	4	2	1	5	3	1	8	3	2	13	5	2	16	6	3	25	8	4	40	14
2.1–3.0	1.1–2.0	1	5	3	1	8	4	2	11	5	2	18	7	3	24	9	4	35	12	†	†	†
3.1–4.0	2.1–3.0	1	9	3	2	11	5	2	16	6	3	23	9	3	32	11	5	47	16	†	†	†
4.1–5.0	3.1–4.0	1	10	4	2	14	6	3	19	8	3	28	11	4	37	14	†	†	†	†	†	†
....	4.1–5.0	2	12	5	3	17	7	4	23	10	4	33	14	5	44	18	†	†	†	†	†	†

*Table not applicable in this region. †Use sample size in first columns to left in which acceptance numbers are shown for acceptable-quality level involved.

TABLE II

Conditions under Which Reduced Inspection May Be Started.—(1) Production must have been continuous during the immediately preceding 2-week period, and inspection under Table I must have been in operation throughout that time; (2) The last twenty sublots inspected must have come from continuous production and must have been accepted as conforming under Table I; (3) The per cent defective (major) computed from the combined first samples from these twenty sublots and all other sublots inspected during the last 2-week period must have been less than the lower boundary of the acceptable-quality range being used for majors (left-hand column of Table I); (4) Same as paragraph 3 with "minor" substituted for "major."

Procedure under Reduced Inspection.—(5) Select first sample, pass sublot, reject sublot, select second sample, etc., as in procedure for Table I, but using sample sizes and acceptance numbers of Table II. (6) In addition to action on individual sublots under foregoing paragraph 5, the first five such sublots inspected must be considered as a group, the second five as a group, etc. (*a*) As the second, third, etc., sublot in each group is inspected, cumulate the number of major defectives (articles which contain major defects) in first samples from that group, and also the number of minor defectives. (*b*) If at any time during the inspection of successive sublots in a group the cumulated number of major defectives, d_e, in the first samples so far inspected exceeds the c_e indicated in Table II, select second sample of size n_2 from the current sublot and determine the number of major defectives, d_2, in this second sample. If $d_1 + d_2$ for the current sublot exceeds c_2, reject that sublot (d_1 is number of major defectives in first sample from current sublot). (*c*) Same as foregoing paragraph (*b*) with "minor" substituted for "major." (*d*) Whenever a second sample is inspected from any sublot (for either majors or minors), the next sublot is to become the first in a new group of five successive sublots.

Conditions under Which Normal Inspection (Table I) Must Be Resumed.—(7) If either (*a*) a sublot is rejected under paragraphs 5, 6*b*, or 6*c*, or (*b*) $d_e + d_2$ determined under either paragraph 6*b* or paragraph 6*c* exceeds the c_2 indicated in Table II, all succeeding sublots must be inspected by Table I until the conditions of paragraphs 1, 2, 3, and 4 are again met.

FIG. 27. Reduced Lot-by-Lot Acceptance Inspection: Double Sampling

LOT RECORD OF SAMPLING INSPECTION

MATERIAL INSPECTED

INSPECTION OPERATIONS

OPERATING DEPT OPERATIONS

INSPECTION SECTION

YEAR	CODE OR P NO	LOT SIZE	1ST SAMPLE		2ND SAMPLE		TOTAL DETAILED		DEFECTS IN 1ST SAMPLE	OPERATOR OR GROUP NUMBER	INSPECTOR'S CLOCK NO.	DISPOSITION OF LOT PASS, REJECT, ETC.	REMARK NUMBER
DATE			SS	DEF	TOTAL	DEF	PARTS	DEF					

FIG. 28. Original Record Used by Inspector for Acceptance Sampling

The normal use of Fig. 26 is satisfactory and adequate only when the process average is equal to or less than the acceptable level $\bar{p}$. If the process average is actually worse than the acceptable average, a large number of lots will be thrown back to the manufacturer, imposing a penalty for poor control. He is, by reason of economy, forced to improve his control.

When the use of Fig. 26 has resulted in a specified run of accepted lots, inspection by Fig. 27 is permitted until results again indicate a poorer level of quality. The footnotes of the reproduced tables outline the procedure.

USE OF CONTROL CHARTS WITH ACCEPTANCE SAMPLING.—Control charts are often maintained for supervising the control of the manufacturing process, using the information provided by the sampling inspection for acceptance purposes. This presents no difficulty. The original record used by the inspector can be of the general form in Fig. 28, corresponding somewhat to that for 100% lot inspection in Fig. 5 in this Section. When double sampling is used, it is necessary to use the fractions defective of the first sample only for control chart purposes.

INSPECTORS' SAMPLING INSTRUCTIONS.—It is usually better to have the choice and design of sampling plans for specific cases in the hands of a quality department. In general, the procedure would call for the submission of a request for a sampling plan when it is felt that the control of quality is good enough to warrant a plan. When the quality department agrees that the control record warrants a plan, it can make a plan layout for the particular inspection item and location, in somewhat the form suggested in Fig. 29.

LAYOUT FOR SAMPLING INSPECTION

No.________ Date________________

Material Inspected____

From Dept. No.____________________ Part No.____________________

For Use By Insp. Sect.____________ Approved By____________ Approval Date____________

LOT SIZE	SAMPLING SCHEME					Inspection Operations
	1ST SAMPLE		2ND SAMPLE			
	N_1	C_1	N_2	N_1+N_2	C_2	
0-50						
51-100						
101-200						
201-300						
301-400						
401-500						
501-600						
601-800						
801-1000						
1001-2000						
2001-3000						
3001-4000						
4001-5000						
5001-7000						
7,001-10,000						
10,001-20,000						
20,001-50,000						
50,001-100,000						

Material to be used on: ______________________________

Attained process average fraction defective________________%

Expected process average fraction defective________________%

Lot tolerance fraction defective ________________%

Maximum acceptable process average fraction defective________________%

Usual lot size ______________________________

Approximate annual output______________________________

Remarks:

Layout issued by____________________ Date____________________

Fig. 29. Layout Form for Sampling Inspection

SECTION 11

PLANT LAYOUT

CONTENTS

SECTION 11

PLANT LAYOUT

THE FACTORY.—The term factory or, more broadly, "manufacturing plant" means a building or group of buildings together with mechanical equipment, machinery, tools, and other physical facilities needed for the production of goods and the physical and mental well-being of its employees. Manufacturing implies organization of the physical and human agencies of production using modern machinery together with the principles of division of labor, specialization, standardization, and interchangeability.

CLASSIFICATION OF MANUFACTURING PLANTS.—Manufacturing industries may be classified according to the nature of the process performed, continuous process, repetitive process, and intermittent process industries. Generally speaking, a continuous process industry is one that is carried on 24 hours per day; a repetitive process industry is one where the product is processed in lots; an intermittent process industry is one that processes items of product when and as ordered. In the repetitive process industry, the lots may follow each other with such regularity as to create a situation analogous to a continuous process industry, except that production is not of necessity carried on 24 hours per day.

Examples are given in the following tabulation:

Continuous Process Industries	Repetitive Process Industries	Intermittent Process Industries
Blast furnaces	Automobiles	Elevators
Brick	Electrical appliances	Hydraulic turbines
Cement	Garments	Locomotives
Coke	Hats	Railroad cars
Glass	Jewelry	Rolling mills
Heavy chemical	Machine tools	Ships
Lime	Millinery	Steam turbines
Pottery	Shoes	
Sugar	Textiles	
	Wood screws	

OPTIMUM SIZE OF INDUSTRIAL ESTABLISHMENT.—The most favorable size for a factory, or industrial unit, can be considered from several points of view. Engineers engaged in industrial operation believe that such an optimum of size can be determined for a particular industry, although it may differ widely between industries. One approach to the determination of this size is to find what size of organization, using existing resources, manufacturing techniques, and organizing ability, produces at lowest unit production cost, when all costs are included which must be covered in the long run.

Factory Buildings

ONE-STORY VS. MULTISTORY BUILDINGS.—The first group of factors of importance in plant layout is that of the relative advantages, and the reasons dictating, the types of construction used for a plant—single-story or multistory.

The study shown in Fig. 1, made by the Austin Co., favors a single-story building. The two buildings compared are essentially the same as regards specifications and requirements of insurance companies. The same unit prices were used. In practice, of course, material and labor costs vary with locality, and ordinarily multistory buildings are erected on more expensive land than that selected for single-story buildings.

Multistory Building		Single-Story Building
72,000 sq. ft.	Total Gross Area	72,000 sq. ft.
Area Lost		Area Lost
2,976 sq. ft.	Columns	1,168 sq ft.
1,512 sq. ft.	Elevators	None
2,160 sq ft.	Stairs	None
3,600 sq. ft.	Approaches	None
3,120 sq. ft.	Outside Walls	1,260 sq. ft.
13,368 sq. ft.	Total Area Lost	2,428 sq. ft.
58,632 sq. ft.	Total Usable Area	69,572 sq. ft.
82%	Per Cent of Usable Area	96%
1/2 acre	Land Required	2 acres
$164,000.00	Cost of Building Complete	$122,000 00
3,000.00	Cost of Land at $6,000 per acre	12,000.00
$167,000.00	Total Price	$134,000.00
$2.27	Price per sq. ft. building, including heating, lighting, plumbing and elevators	$1.70
2.77	Price per Usable sq. ft. of building	1.76
2.85	Price per Usable sq. ft., land and building	1.93

It should be borne in mind that building costs vary in different localities, but the relative costs between the two basic types will remain comparable.

FIG. 1. Cost Comparisons Between Multistory and Single-Story Factory Buildings Having the Same Gross Floor Area

FACTORS THAT DETERMINE TYPES.—The factors indicating and the advantages of **one-story construction** are:

1. Low cost of ground area.
2. Availability of land for expansion
3. Less time to erect.
4. Less area lost in sidewalls and columns clearance and for elevators, stairs, approaches to them, etc.
5. High floor loads caused by equipment or product.
6. Greater flexibility in accommodating layout changes.
7. Possible greater efficiency in routing and handling equipment.
8. Supervision easy and effective.
9. Maximum use of daylight and natural ventilation possible.
10. Hazardous and objectionable occupations easily isolated.
11. Lower over-all operating costs.

The factors indicating and the advantages of **multistory construction** are:

1. High cost of ground area.
2. Limited area of site.
3. Natural topography of site may permit entrances on different floor levels.
4. Ease of expansion if properly foreseen.
5. Limited need for high floor load.
6. Majority of product and equipment light in weight and of small bulk.
7. Possible better coordination of departments in a vertical plane—handling distances may be reduced and gravity flow utilized.
8. In some locations, less dirt and better lighting and ventilation possible on upper floors.
9. Lower heat loss through roof.

GROUPING OF BUILDINGS.—Past practice has been to lay out buildings corresponding to shapes of such letters as U, H, E, T, L, and F, depending on departmental problems and flow of materials through the plant. All of these shapes lend themselves to enlargement, and much can be said for such groupings. More recently, many companies have adopted a **solid block shape** with all operations on a single floor and under one roof. George Nelson (Albert Kahn, Inc.) says:

Multiplicity of buildings increases construction costs, due to the number of exterior walls, the intervening courts occupy space which could be used more advantageously for production, and their maintenance is expensive. Heat losses through exterior walls are also greater in a group of buildings.

The main criticism advanced by the Kahn office, however, is on the grounds of flexibility. As processes change, as departments shrink and expand, or as new departments are added, the advantages of the single structure become apparent. While this represents a modern viewpoint that must be considered, many engineers regard the question of number of structures as a many-sided question which is debatable.

Fundamentals of Plant Layout

BASIS OF LAYOUT.—Layout of a plant, both of departments and of machines, should be the **expression of a purpose.** To this end the processes through which materials pass, their sequence of flow of work, machines and equipment required for the anticipated volume, and location of many auxiliary departments—receiving, shipping, toolroom, lavatories, and others—are vital. But the practical and psychological aspects of other factors, the building structure, heating, ventilating, lighting, noise control, and the like, must receive thorough consideration.

Although essentials of plant layout are substantially the same for all industries, in application results will vary depending upon type of product, size of plant, variety of output, and building limitations imposed. Ideal circumstances exist when an entirely new plant is to be erected, but seldom is this the case. More commonly, the **layout must be fitted into existing buildings** with their inherent limitations. The problem facing the production engineer is usually one of relayout to improve the operating efficiency of manufacturing processes, or to provide for making new products.

Purpose of Layout.—Arthur F. Murray, Works Manager of Electrolux Corp., at an annual meeting of the American Society of Mechanical Engineers indicated the purpose and economics of manufacturing layout as:

With increased production of existing products, layout procedure is easier and surer than with new items. Where cost reduction is a major factor, equipment studies, detailed cost studies, and review of design possibilities are called for. Shrinking of layouts may occur because of reduced market demands or necessity for retaining older models in production on a reduced scale. Consolidated production of several similar products, some with increasing and some with decreasing demand, may be beneficial to both conditions. Relocation, particularly from one operating staff or plant to another, may provide new products to the receiving group in the new location. Analysis of fundamentals presents exceptional opportunity for manufacturing cost reduction in relocated layouts.

The production schedule, starting date, maximum and minimum daily load, seasonal fluctuation, and life of design have important effects on layout. Short time before start of production, short period of use, or wide seasonal fluctuations indicate employing well-tried methods with available or easily procured equipment of considerable salvage value, as well as dependence on existing feeder section and outside suppliers. Unusual operations or processes requiring development should be shunned if product must be produced quickly for a changing market.

These factors, together with the nature of the product and the geography of site, applied to any manufacturing problem, will determine the type or even the necessity of a new layout.

Stages from Jobbing to Mass Production.—In the same paper Murray points out that as products gain in popular acceptance they tend to pass through five stages, in which one of the following procedures is indicated with respect to layout:

1. Assign to existing manufacturing divisions of the organization, tools to be used on existing fabricating, assembly, and test facilities. No layout changes are required.
2. This is similar but a few items of capital equipment are required or a few operations must be performed by outside suppliers. Minor changes in layout are required.
3. A special assembly and test layout is required but machining is done in general departments as in classes 1 and 2. Considerable layout work will be required.
4. Straight-line set-up is desirable for assembly and test, machining of major parts and certain minor parts likely to cause quality or production controversies. Still more layout work is required.
5. Approximately complete straight-line production, or the independent plant, including certain feeders.

Very few products go the whole way from class 1 to class 5. It is evident that by careful classifying and grouping, diversified products may be given many of the advantages of straight-line or mass production and still retain flexibility of control.

Feeder Sections.—The following is also from Murray's discussion. There is a general trend to include many typical feeder, or parts, operations in sequence layouts and to provide subfeeders for some individual operating divisions apart from general service departments. The reasons

are: (1) that increased size of assembly and feeder units eliminates personal contact and increases costs because of double inspection and extra material handling and storage; (2) better specifications, metallurgy, and fabrication give more uniform materials; (3) there exist more scientific knowledge of processing and better control instruments; (4) improved equipment has removed objections to locating certain units in production lines. Studies for feeder installations are made in the same way as for the main product.

The natural feeder sections of any plant are those requiring large volume, special processes, or having nuisance factors. Such sections divide into three general groups: (1) items frequently obtained from outside suppliers and usually preliminary to machining operations; (2) operations more intimately associated with machining and assembly, but having characteristics similar to group 1; (3) general detail machining, grinding, painting, dipping, baking, etc.

Studies for Layout.—The importance of good layout of departments and machines (Fact. Mgt. & Maint., vol. 101) lies in the fact that it brings about the following cost-saving advantages. It

1. Provides definite lines for travel of work.
2. Gives the shortest feasible distance of travel.
3. Reduces the amount and cost of materials handling.
4. Cuts down over-all time of work in process.
5. Reduces amount of work in process.
6. Decreases inventory in storerooms.
7. Brings about more efficient utilization of labor and equipment.
8. Conserves floor area.
9. Increases the efficiency of mass production.
10. Simplifies work routing.
11. Reduces the labor and cost of production control.

A study along the following lines, rearranged here for present purposes, is suggested by Moore (Mech. Eng., vol. 47) as a preliminary to final action in matters of layout and arrangement, and equipment selection:

1. Study of manufacturing schedule to determine number and variety of subassembled or finished units to be produced.
2. A list of materials or parts comprising product to determine which ones will be manufactured and which ones purchased and stored.
3. Deciding on desired capacity of plant and equipment for lines of products made or proposed, and estimated future capacity.
4. Listing of manufacturing and assembling operations necessary to produce a finished or subassembled unit.
5. Sequence of operations in manufacturing and assembly departments in order that departments and equipment shall be in logical and convenient relationship for progressive flow of materials.
6. Production equipment or plant facilities needed to manufacture the proposed quantity and variety of products, including any special provisions or structural features which will facilitate production.
7. Time interval required between successive operations, if any, to check need for and location of storage space.
8. A review of any hazardous, dust- or fume-producing, odorous, or otherwise objectionable operations entering process to determine whether departments in which such work is done should be isolated from the standpoint of safety, noise, or special process needs.
9. Space requirements per department to house production equipment and provide area needed for aisles, storage, or auxiliary facilities.

10. A summary of floor space needs of plant, which areas can be proportionately increased for different departments, based on an assumed future capacity after a certain period of years, thus providing an approximate basis for estimating the total space requirements and development of a suitable layout for ultimate plant development.
11. Recheck of proposed layout with other departments, including engineering, manufacturing, time and motion study, methods engineering, inspection, plant engineering, and any other interested divisions, to remove unsatisfactory proposals and get the best composite layout.

The number of shifts to be employed is also obviously an important factor in layout.

Operating Effectiveness.—Layout of departments, their relation to each other, and layout of machines must be right or production will be hampered, inefficient, and usually reduced. Under such conditions long hauls, backtracking, and crisscrossing of work exist, making it difficult to control the progress of material through the plant. Material is repeatedly delayed in transit or lost and interruptions and stoppages in operations occur more frequently. Machine arrangement also may have a marked effect upon the ease with which operators work, handling time and effort necessary, space required for work in process.

Cost of Operations.—In addition to making the problem of operation more difficult, long hauls, backtracking, crisscrossing, and loss of control over flow of materials unnecessarily increase costs. Not only is cost of materials handling greater, but also there are increases in investment in work in process, and in costs or production control, inspection, and counting. Efficient machine arrangement often makes it possible to replace two or more machines with one, or to have an operator run more than one machine, thus reducing investment in equipment, space requirements, and labor costs.

INFLUENCE OF PROCESSES ON PLANT LAYOUT.—If a layout is to be the expression of a purpose, it must be built around the process concerned. Processes, then, must be given prime consideration in laying out a plant.

In **continuous process industries,** where operation follows on operation without interruption—petroleum refining, for instance—it is apparent that the processes and their sequence by their very nature almost dictate the layout. In **interrupted process industries,** the relationship of operation to operation is not always clear, nor is it constant. Where a number of different products are manufactured, the sequence of operations is seldom the same for all so that relationship of department to department is far from dictated. Yet in many instances individual processes will have definite layout requirements.

On the one hand, processes requiring unusually **heavy floor loads,** due to machines or product, will require a ground- or first-floor layout to prevent excessive building vibration or high construction cost. Heavy punch presses such as are used in the automotive industry are almost invariably located on the ground floor, or in single-story buildings, and tractors, locomotives, large turbines, large pumps, generators, transformers, and the like are built in single-story buildings with ample headroom for cranes.

On the other hand, processes which lend themselves to **gravity handling of material** may make advisable a multistory building with

PROCESS FLOW CHART
MODEL 33 RECEIVER
OLD LAYOUT

TRAVEL (Feet)	OPERATION	DESCRIPTION
	▼	Raw stores
	1	Load on truck
655	o	To dept 77
	2	Blank and pierce
27	o	To press
	3	Pierce 2 locating holes
24	o	To press
	4	First form
14	o	To press
	5	Second form
6	o	To press
	6	Finish form
20	o	To elevator 43-1
15	o	Up one floor
19	o	To wash
	7	Wash
57	o	To elevator
15	o	Up one floor
	▼	Wait for electric truck
1015	o	To dept 75
	8	Drill and assemble inserts
4	o	To floor
64	o	To riveting machine
	9	Rivet inserts
223	o	To bench
	10	Burr rivets and rear end
214	o	To handscrew machine
	11	C-bore and face front end
173	o	To wash room
	12	Wash
125	o	To drill
	13	Drill 3 holes
125	o	To wash
	14	Wash
64	o	To powermill
	15	Powermill loading opening
72	o	To wash
	16	Wash
211	o	To handmill
	17	Handmill recoil slot
93	o	To press
	18	Shave bolt lug slot
82	o	To profile
	19	Profile bolt slot
174	o	To wash
	20	Wash
335	o	To bench
	21	Finish file
251	o	To tapping machine
	22	Tap front end
66	o	To wash
	23	Wash
343	o	To bench
	24	Inspect
105	o	To elevator
15	o	Up one floor
172	o	To elevator
15	o	Up one floor
600	o	To polishing
	25	Polish outside
200	o	To bench
	26	Finish file
307	o	To bench
	27	Inspect
935	o	To dept 52
	28	Brown
171	o	To bench
	29	Inspect
10	o	To oil
	30	Oil
126	o	To elevator
45	o	Up 3 floors
120	o	To part stores
	▼	Part stores
240	o	To bench
	31	Assemble

Fig. 2. Flow Process Chart of Operations in Manufacture of Receiver
(Fact. Mgt. & Maint.)

PROCESS FLOW CHART
MODEL 33 RECEIVER
NEW LAYOUT

TRAVEL (Feet)	OPERATION	DESCRIPTION
	▼	Raw stores
150	o Crane	To press
	1	Blank and pierce
10	o	To press
	2	Pierce 2 locating holes
10	o	To press
	3	First form
10	o	To press
	4	Second form
10	o	To press
	5	Finish form
323	o	To drill
	6	Drill and assemble rivets
18	o	To riveter
	7	Rivet inserts
2	o	To bench
	8	Burr rivets and rear end
14	o	To handscrew machine
	9	C-bore and face front end
30	o	To wash tank
	10	Wash
24	o	To drill
	11	Drill 3 holes
14	o	To lathe
	12	Line ream 3 holes
16	o	To powermill
	13	Powermill loading opening
8	o	To handmill
	14	Handmill recoil slot
4	o	To press
	15	Shave bolt lug slot
6	o	To profile
	16	Profile bolt slot
0	o	To wash
	17	Wash
8	o	To bench
	18	Finish file
16	o	To tapping machine
	19	Tap front end
8	o	To wash
	20	Wash
4	o	To bench
	21	Inspect
8	o	To jack
	22	Polish
3	o	To press
	23	Stamp number
18	o	To bench
	24	Finish corner and inspect
208	o	To brown
	25	Brown
20	o	To bench
	26	Inspect
80	o	To assembly
	▼	Before assembly
	27	Assemble

SUMMARY

	Old		New		Dif	
Total oper	31		27		4	
Total trav (Ft)	7547		1058		6489	
Total moves	No	Dist	No	Dist	No	Dist
By elec truck (K)	9	4035'	2	531'	7	3504'
By hand truck (H)	22	3250'	-	-	22	3250'
By man (M)	6	157'	23	427'	17	270'
By conveyor (C)	-	-	1	100'	1	100'
By elevator (E)	5	105'	-	-	5	105'

◯ Denotes an operation
o Denotes a transportation
▼ Denotes a temporary storage
▽ Denotes a permanent storage
▭ Denotes an inspection

FIG. 3. Flow Process Chart of Operations in Inspection and Packing of Boys' Tennis Shoes
(Fact. Mgt. & Maint.)

FIG. 4. Qualitative Flow Diagram of a Molasses Distillery (Chem. & Met. Eng.)

related departments or operations one below the other. Small products, liquids, and powders are easily handled in this manner. A flour mill, for instance, is almost wholly dependent upon gravity **feed** for downward movement and small material elevators for upward movement, the predominant flow of the material being up and down throughout the processing.

Some **meat-packing** concerns slaughter on the top floor of a five- or six-story building, driving the animals up a ramp to the slaughter pens, thus using animal energy to get the raw material to a point whence its further flow is by gravity.

A further influence the process may have on the layout is to segregate certain processes or certain departments from the remainder of the plant. Processes which are usually **objectionable or dangerous** from the standpoint of noise, heat, dust, fumes, vapors, acids, or fire and explosion hazards which cannot be controlled at their sources, should be placed in separate rooms or separate buildings.

Processes in which it is advisable to utilize daylight to the best advantage, other factors being equal, should be located in single-story buildings, or on the top floor of a multistory building. Drafting rooms, photographic departments, and general offices are commonly located on a top floor to secure good daylight. Fluorescent lighting in some cases, however, is offsetting this practice.

FLOW OF MATERIAL AND LAYOUT.—Layout of the plant should be such as best to facilitate the flow of material through it. In a single-product plant where but one sequence of operations is required, this objective is readily accomplished by so placing departments that each subsequent operation is adjacent to the preceding operation. In a multiproduct plant where one department may be called upon to process numerous products, the layout becomes more complex. Here it may be impossible to locate subsequent operations adjacent to one another, but still the material flow from department to department should not be lost sight of.

Visualization of flow is at times difficult but may be materially aided by flow process charts and by flow diagrams. The flow process chart

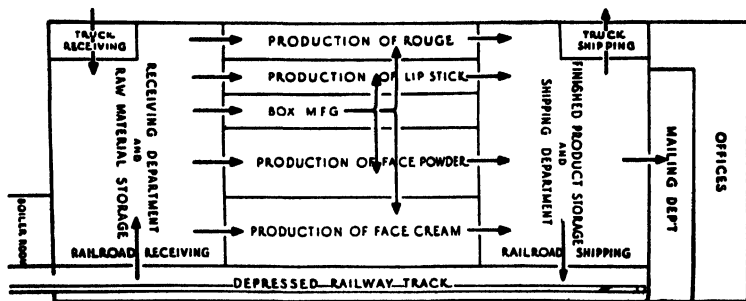



FIG. 5. Product Flow Diagram of Lady Esther, Ltd.
(Architectural Book Publishing Co.)

Fig. 6. Departmental Arrangement of a Turret Lathe Shop
(Ralph E. Flanders)

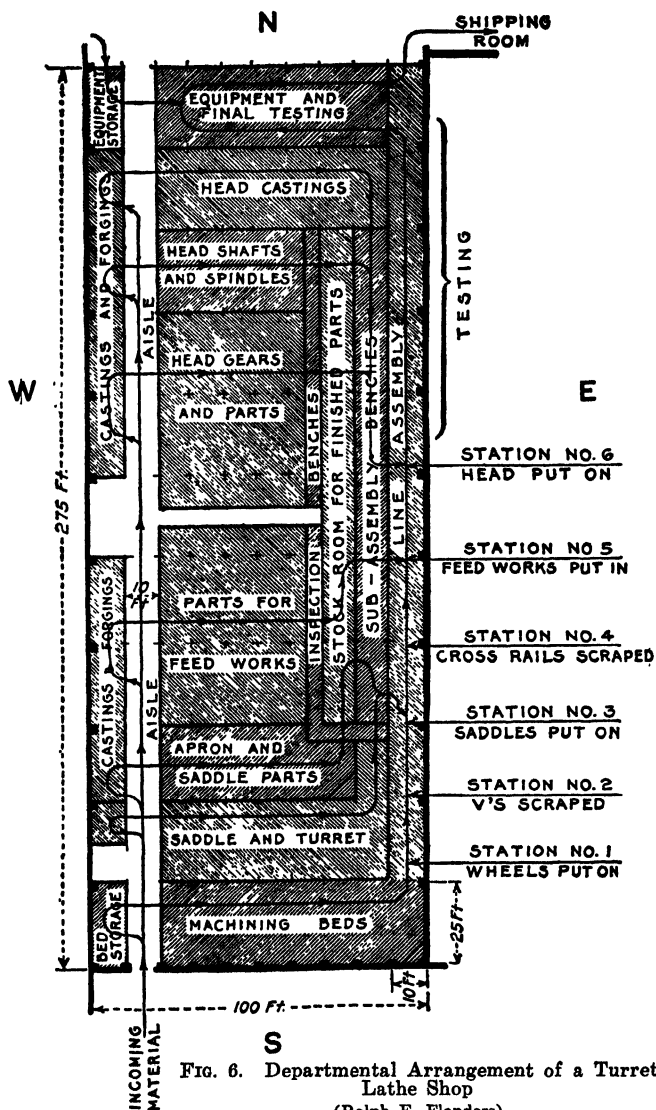
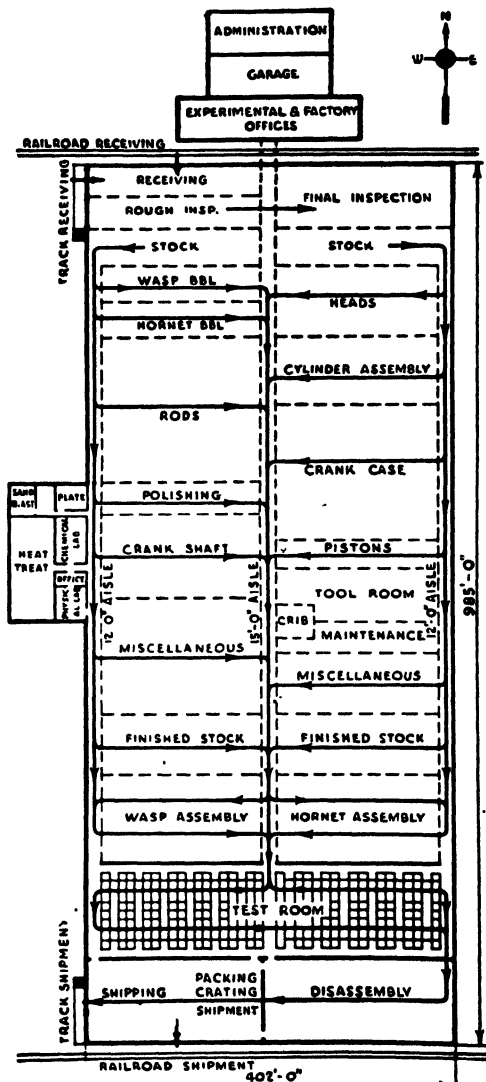



FIG. 7. Flow Diagram of Pratt & Whitney Division, United Aircraft, Inc. (Architectural Book Publishing Co.)

shows, by the use of symbols and brief descriptions, operations, inspections, transportations, and storages pertaining to a given material or product as it passes through the plant. Such a chart is shown in Fig. 2. Flow process charts also may be developed to include operations on many parts and their relation to one another as shown in Fig. 3. While the flow process chart is valuable in assisting one to visualize what is taking place in the plant and the exact sequence of each operation, it is particularly valuable in analyzing present manufacture with a view toward improving an existing layout.

A flow diagram is a second aid to visualization of a plant layout, and shows to scale a plan view of the plant with arrows to indicate flow of material from department to department. Typical flow diagrams are shown in Figs. 4 to 11.

In Fig. 11 a pictorial method of indicating the layout is used to show the flow of work in a motor plant. The material comes in at the left, flows progressively toward the right, except for short lateral flows, and leaves in the form of a finished product at the right. Mechanical

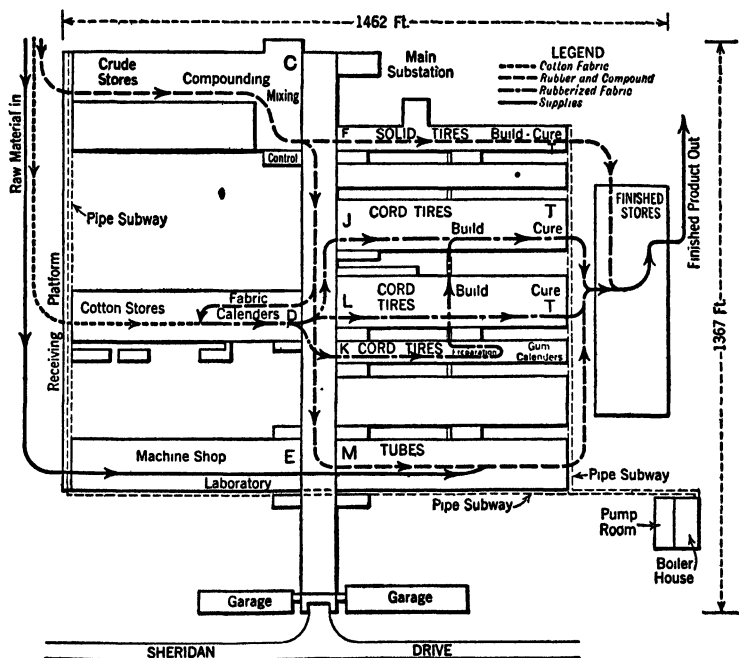



Fig. 8. Layout of Automobile Tire Plant and Routes of Materials
(Dunlop Tire & Rubber Corp.)

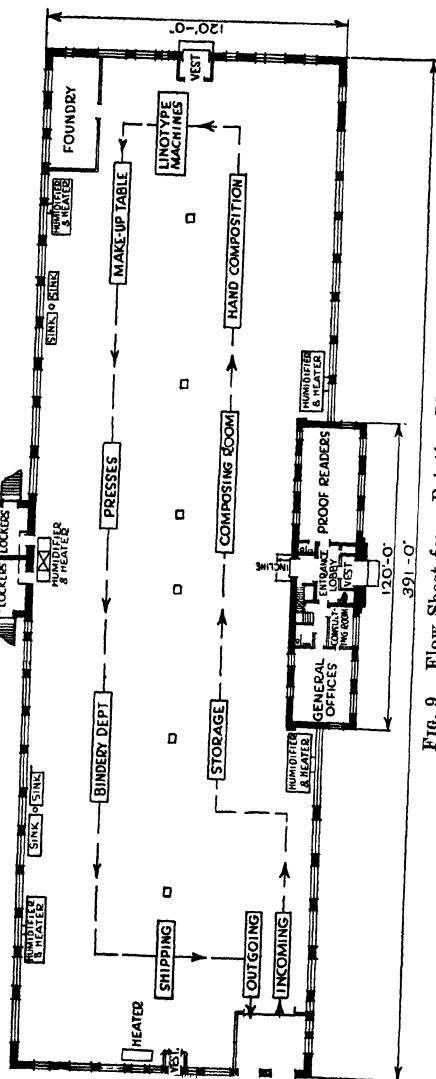



FIG. 9. Flow Sheet for a Printing Plant
(The Architectural Record)

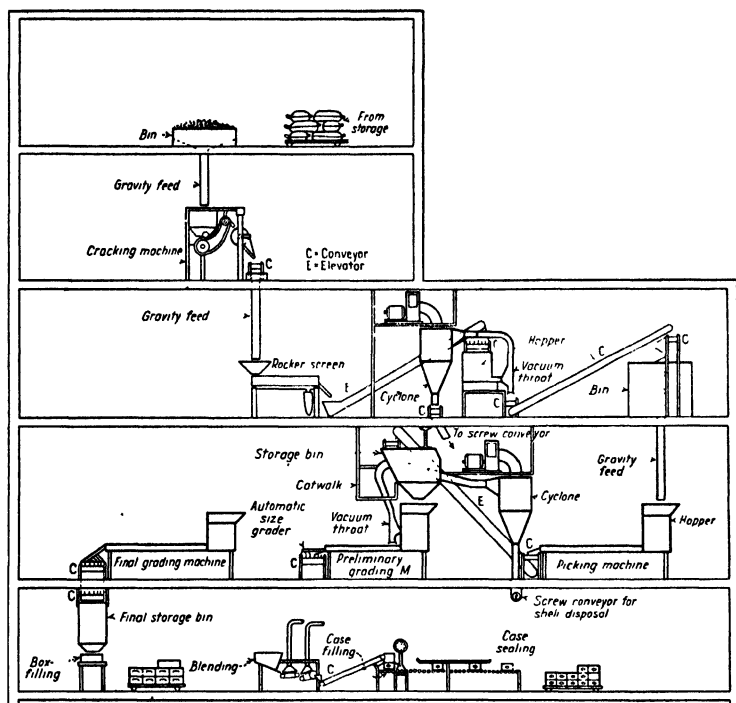



FIG. 10. Flow Diagram of Walnut Shelling Process of California Walnut Growers Assn.
(Food Industries)

handling is used throughout (Mallick, Plant Layout—A New Must for Industry, Westinghouse Elec. & Mfg. Co.).

ROUTE SHEETS AND OPERATION SCHEDULES.—In the development of products and planning for their manufacture, decisions are reached which have an important bearing on the efficiency and cost of manufacturing. Product designs should be analyzed by the manufacturing department before final approval, to eliminate features which would prove troublesome in the factory, or would add to the cost. For each part, subassembly and assembly, there will be prepared an operation list indicating operations needed, where performed, their sequence, machines, fixtures, and tools used, and other necessary information (see Fig. 12). This record serves also as a master route card for the part or assembly. A summary of similar data for all parts produced, with information of the time required for each operation or process, will aid

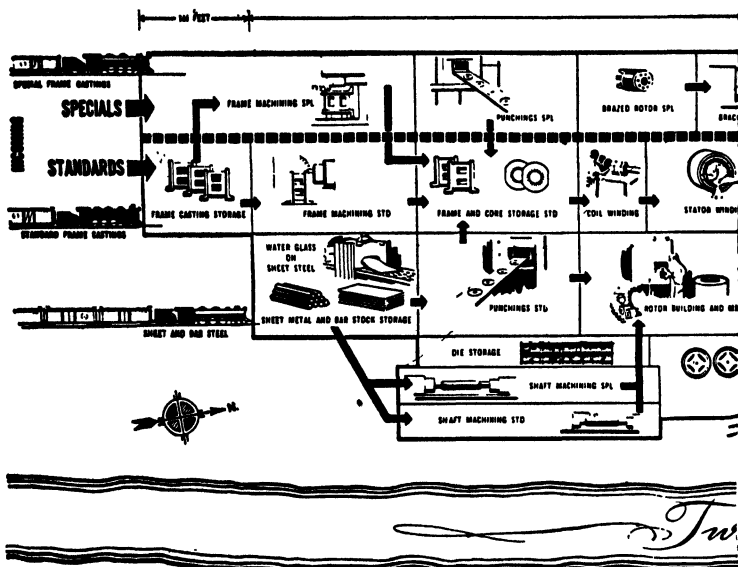
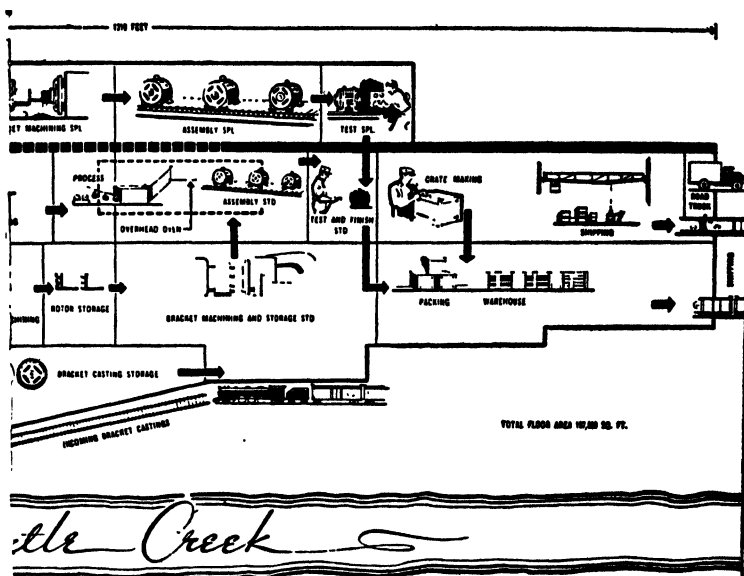



FIG. 11. Flow Diagram of Layout of a

in determining the amount of machine equipment needed for each department. General factors to be considered are:

1. Volume of production.
2. Maximum capacity of equipment.
3. Hours of work planned for.
4. Normal production capacity to be used when scheduling and dispatching work, including allowances for working arrangements, idle time for set-ups, repairs, etc.

A **time analysis** of different operations, together with the necessary time between operations, will supply the over-all manufacturing time. The duration of the manufacturing cycle will be less for parts moving forward a unit at a time than for lots. Some operations require a greater length of time to complete than others and if parts are handled in lots, congestion may be caused at some points and idleness at others unless work is carefully scheduled and machine capacities provided to meet schedule demands. Fig. 13 shows the results of an analysis of machine times for a series of operations on a lot of 30-dozen refrigerators with a 40-hour manufacturing cycle, and indicates balanced capacity of several work stations. As noted, it is not necessary to await the completion of an operation upon all parts in a lot before starting the succeeding operation. In order to **maintain the manufacturing cycle** established, the size of lots for various models was varied. The objective was to have the same time allowance for a standard lot of any type or size.

Westinghouse Industrial Motor Plant

C. D. Hart, of the Western Electric Co., considers it important that, in the construction and layout of a building for certain processes, some consideration should be given to the possibility of improved processing methods being introduced at a later period and a chance of their being fitted into the former layout satisfactorily.

Machine Layout

ESSENTIALS OF MACHINE LAYOUT.—As accuracy of work can be no better than accuracy of the tool that produces it, so the efficiency of a plant can be no better than the calibre of its machine layout. Proper machines must be provided to handle the volume of work expected, and their arrangement must be such that work will flow smoothly from operation to operation without excessive delay. The important space allowances are these:

1. Room for the worker operating the machine or machines.
2. Allowance for projection, overhang, or overtravel of machine parts, such as the table of a planer.
3. Allowance for projection of work, such as bars fed to a screw machine.
4. Room for industrial trucks to deliver and remove parts that are large, or are handled on skids, pallets, or in tote boxes.
5. Space for floor conveyors or chutes in a fixed product layout.

6. Room to get large work on and off machines. Often this handling is done by a hoist, jib crane, or overhead traveling crane for the use of which there must be the proper space allowances.
7. Area for the storage of the maximum-sized lots of work to be done, and for work completed and awaiting removal. Most frequently these areas are necessary in the actual doing of work to provide the place from which to get parts for processing and to put them as they are finished.
8. Place for workbench, work table, tool rack, or other equipment containing the worker's tools, supplies, drawings, etc.
9. Room to get at any part of the machine which may require adjustment or changing in the course of operations.
10. Quick access to safety-stops in case of accident to worker or breaking or jamming of the machine.

MANUFACTURING LAYOUT RECORD

DEPT.	OPERATIONS	TOOLS AND SPECIFICATIONS	MACHINES
338	Perf. (4) .093" holes and Blank	P&D C-16374	#3 Bliss
	Tumble	Sawdust and pumice	Tumb. bbl.
	Flatten	P&D C-57827	#19 Bliss
641-2	Inspect		
263	Count		
333	Bore 53/64" hole	Jig C-2295 Use gauge pin assembly Det #16 Gauge plate Det. #2 in pos. H. Det. #7 in position "A" and gauge pin, Det. #9 in position 1 and 8. Combination c'bore and c'sink tool C-48318, ground to suit	1 Sp B.D.P.
	Grind off c'boring burr in	Disc C-72199	Disc. Motor
	Countersink (4) holes	Sp. Gr. Drill	1 Sp. B.D.P.
	Remove Grinding burr in 53/64" hole	Scraper	Bench
642-3	Inspect	Gages	
251	Count		
343	Acid Dip	Spec. 50029, Method #9-B	
	Dry	Spec. 50032, Method #1-A	
643-1	Inspect		
255	Count		
230	Store		

DELIVER IN CONTAINER No. 782 UNLESS OTHERWISE SPECIFIED

ISSUE 2-19	SHEET NO.	NAME OF PART Face Plate	DRWG. P-88235
REPL. ISSUE 12-28	SHEETS IN SET	APPARATUS Misc. Signals	

FROM STORE	QUANTITY PER 1000 PARTS	RAW MATERIAL NUMBERS	PART NO. OR DESCRIPTION OF STOCK	DELIVER TO DEPT.
229	35.#		1064" × 1-9/32" × 72" Grade "A" Half Hard Brass Sheet, Spec. 57504 53 pcs. per sheet 1-9/32" × 72" (On 1-11/32" centers) 18.87—sheets 1-9/32" × 72" per M Pos.	338

ISSUED BY PLANNING DIVISION | DO NOT REMOVE THIS LAYOUT FROM BINDER

FIG. 12. A Typical Manufacturing Analysis

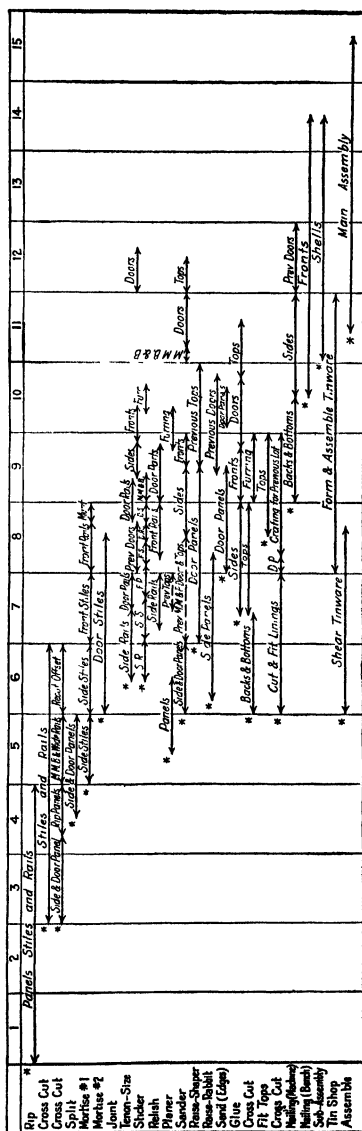



FIG. 13. Graphic Schedule Showing Standard Operation Times, Sequences of Operations, and Operation Release Points for a 30-Dozen Lot of Refrigerators

11. Access to the machine for inspection, maintenance, oiling and repairs, and for the removal of any part, such as a shaft, without moving the machine from its position.
12. Allowances made necessary because of proximity to columns, walls, partitions, stairways, elevator approaches, etc., which may require the providing of extra area, or for the waste of area, because of the size or shape of the machine, or some factor in its operation.

THE PRODUCTION CENTER.—A "production center" constitutes the total area occupied by a machine plus the floor area necessary for the storage of material at the machine and for getting it into and out of the machine, for auxiliary tools, benches, cabinets, and the like, for the operator to work with freedom, for repairs and maintenance of the machine, and for safety provisions. Figs. 14 and 15 show two illustrations of production centers. In the Westinghouse Electric & Mfg. Co. the term "work station" is used.

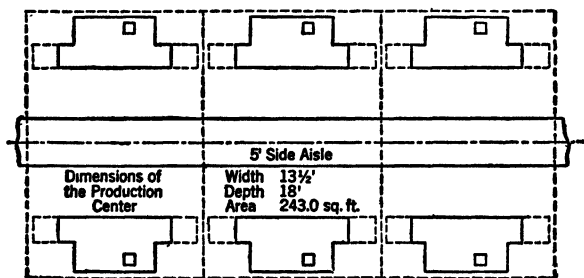



FIG. 14. Layout Arrangement for a Group of Six Norton Cylindrical Grinders Showing the Location of the Machines and the Size of the Production Centers

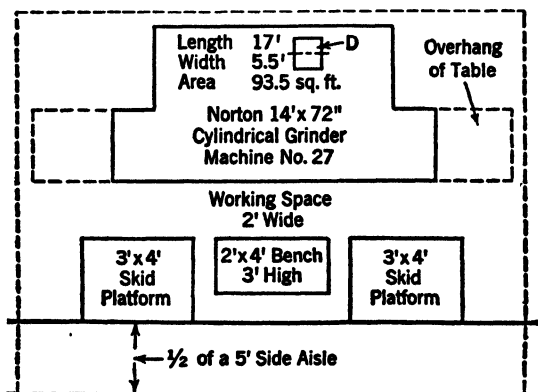



FIG. 15. Layout of Production Center for a Norton Cylindrical Grinder

MACHINE TEMPLATES.—At best, laying out of a machine floor is a cut-and-try problem. Templates are an invaluable aid in planning such a layout or in making changes in existing layouts. These templates are drawn to an appropriate scale (⅛ in. or ¼ in. to the foot is common) showing the projected floor areas of the machines to be used, table overhangs, stock projections, and the like. The templates may then be cut out and moved freely on a scale drawing of the allotted floor area, and arranged and rearranged until a suitable layout is obtained. The layout may be reviewed and checked by others to provide for all known contingencies, thus avoiding possible costly layout errors which otherwise would have to be corrected after the machines are actually placed. The **template layout** may be used as a means of viewing the manufacturing plant as a whole and as a starting point on which later alterations may be planned. A sheet of templates which may be used to represent the machines indicated is shown in Fig. 16 (Millard, Dept. of Ind. Engr., Cornell Univ.). A convenient practice of the Westinghouse Electric & Mfg. Co. is to have the templates show the clearances in dotted lines and only the machines proper in solid lines.

Many companies use the above plan. In larger companies there are often entire plant layout departments staffed by engineers who are continually engaged in studying manufacturing procedures with the object of simplifying operations and layouts. Template layouts are made of all departments and all machines, equipment, materials handling installations, etc. The unit templates are thumbtacked in place, or held by scotch tape or by white rubber cement which permits ready removal and transfer, and are rearranged whenever changes in product or in operations or sequences are made. In fact, such changes are planned and laid out by the template method before being physically put into effect.

The boards containing the templates are often sectional so that any portion carrying, say, a departmental layout may be removed, worked on separately, and even taken out to the actual department to aid in the study or the actual rearrangement. As soon as any change is contemplated it is first worked on the board, or boards, to ascertain the effect on all associated or related operations, so that when the change is completed there will be an improvement without adverse effects on other branches of processing. Such methods notably are used with outstanding success in the Plymouth Division of the Chrysler Corporation.

ROUTE MODELS.—Another frequently used device for planning layouts is the route model. Taylor, Gilbreth, and their associates found such models valuable means for convincing plant managements of the advantages of changing procedures to simplify manufacturing, save production time, and cut operating costs.

Design.—A route model may be made up merely of a board containing the template layout, to scale, of a group of machines, a department, or the floor of a single-story factory, or it may be built up to show the floors of a multistory factory in their respective positions, with template layouts of the equipment on each floor. In cases where a more elaborate, graphic, and impressive presentation is needed, the templates are sometimes replaced by small wood or plastic models simu-

No.	Name	Width	Length
100	Carburizing Furnace	6'-0"	7'-0"
101	Continuous Pickler	7'-0"	41'-0"
102	Continuous Quench Tank..	5'-0"	Variable
105	Draw Oven	13'-0"	73'-0"
106	Hagan Annealing Furnace.	10'-0"	63'-0"
107	*Mahon Batch Washer.....	4'-6"	8'-0"
108	*Mahon Continuous Washer	5'-0"	Variable

Fig. 16. Template Forms Used to Represent Machines When Planning a Machine Layout

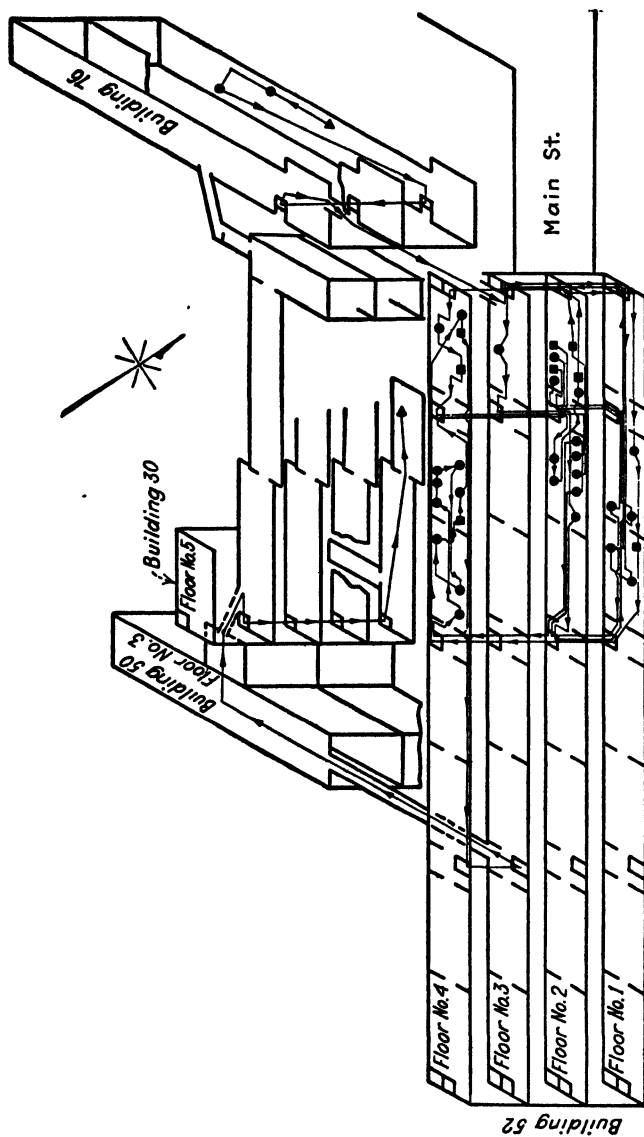



Fig. 17. Original Flow Diagram of a Specific Part Under Manufacture

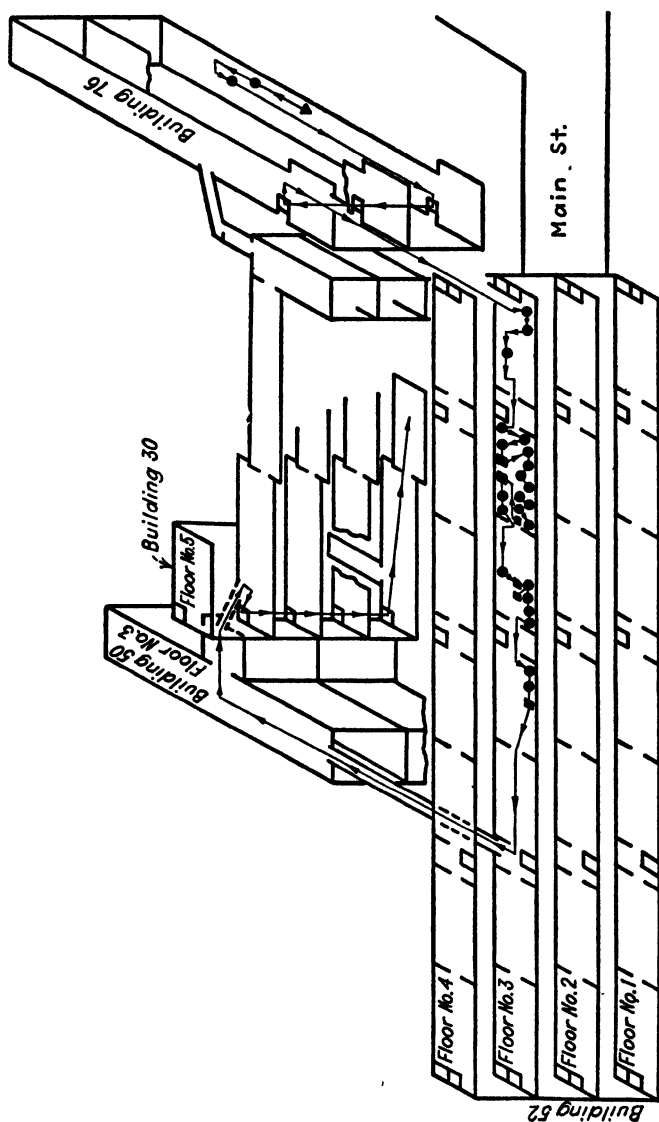



FIG. 18. Schematic Drawing Showing Flow Under Proposed Rearrangement in Present Buildings

lating the actual kinds of equipment. Such route models are expensive and would be used either as permanent portrayals of layout for informational or training purposes, or to "sell" the idea of relayout programs to top executives. In certain cases companies negotiating to install a considerable quantity of expensive equipment in the plant of a pro-

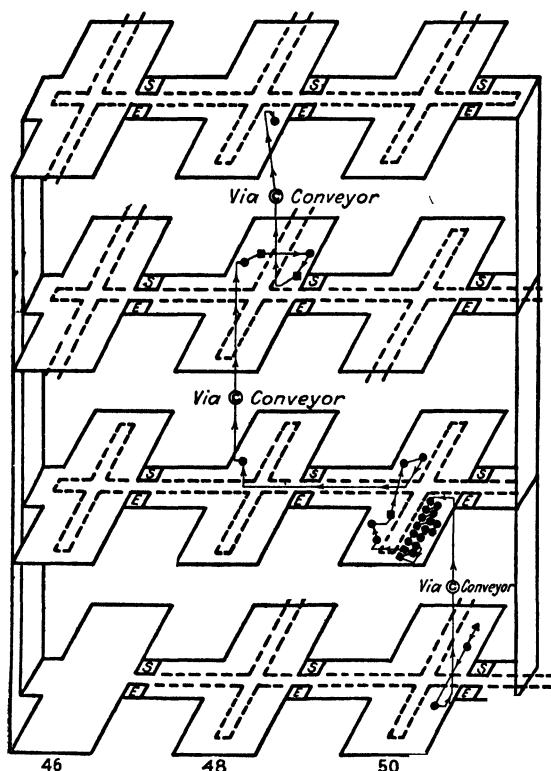



FIG. 19. Schematic Drawing Showing Flow of Same Part as in Figs. 17 and 18, but with Proposed Rearrangement of Machines in New Buildings

spective buyer have made route models by the use of these miniature replicas of the machines.

Layout of Routes.—The route model, in addition to templates or replicas of equipment, has on it colored strings or ribbons tracing the sequences of operations on parts, subassemblies, and assemblies. These strings start at the origin point of some process or route for a material or part and follow through to the completion of the chain of operations.

The route covers transportations by industrial trucks, conveyors, cranes, etc., and enables the production engineer to see how many floors are traversed in each chain of operations, what distances are traveled, what machines are involved, and the ultimate delivery point of the item. From this study, and data on the quantities produced, sizes of lots, continuous or intermittent nature of flow of work, the engineer can determine whether changes in layout or changes in the routing of the operations, bring the work all on one floor, cut down the distances traveled, reduce the number and extent of handling, increase production or reduce the time of the manufacturing cycle, and lower manufacturing costs.

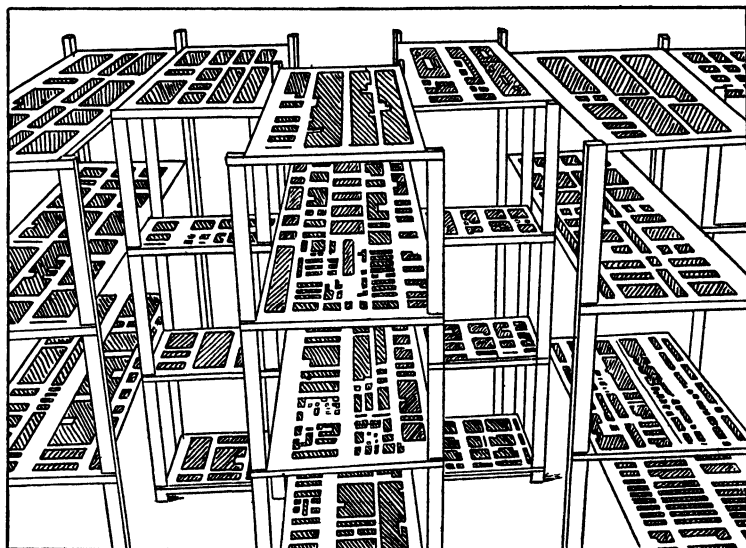



FIG. 20. Drawing of Route Model Constructed According to Flow Laid Out in Fig. 19
(Fact. Mgt. & Maint.)

Figs. 17 to 20 show the plan of study of a proposed relayout of equipment and simplification of processes through the use of schematic flow-of-work drawings (Mogensen, Plant Layout, Factory Management and Maintenance Plant Operation Library). Fig. 17 represents the original flow and Fig. 18 the proposed new layout and flow in the same buildings. In Fig. 19 is shown a schematic drawing of a layout for the work in proposed new buildings. To present this latter new method in a still more vivid form, however, and work out the details of the template layout, a building route model, illustrated by the drawing in Fig. 20, was constructed. It corresponds to the schematic flow diagram in Fig. 19, a layout in three four-story buildings.

DEPARTMENTALIZATION AND MACHINE LAYOUT.—Fundamentally there are two distinct methods of machine layout as effected by the arrangement of departments for manufacturing. In one, referred to as **process layout,** or functional layout, manufacturing is departmentalized according to the processes employed in production. Like machines or like processes are grouped in departments by themselves, all drilling equipment in one department, grinding in another department, welding in another, and so on. The product being manufactured must be moved from department to department as it progresses from raw materials to finished product. In the other form of layout, referred to as **product layout,** or straight-line layout, the machines required to perform all of the operations on a given product are grouped in a department in the sequence in which the operations are performed. The product remains in the department until all manufacturing steps have been performed. Fig. 21 (White, Dept. of Adm. Engr., Cornell Univ.) shows the essential difference between product and process lay-

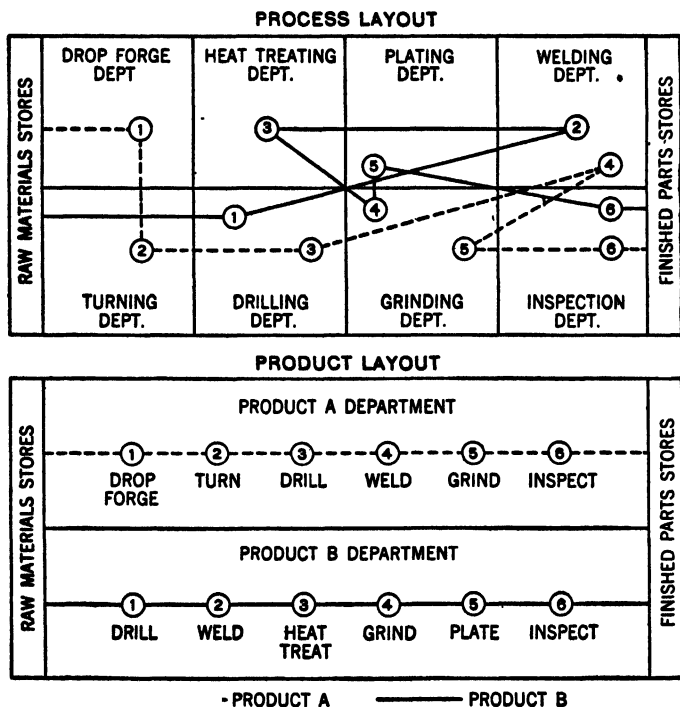
PROCESS LAYOUT

PRODUCT LAYOUT

Fig. 21. Diagram Showing Difference Between Process and Product Machine Layouts

outs. In many cases it is not feasible or practical to adhere strictly to either a process or a product layout, but rather a combination of the two is required.

PROCESS LAYOUT.—Where the product is not and cannot be standardized, or where the volume of like work produced is low, a layout according to the processes performed is practically required. Such a condition requires **flexibility in the sequence of manufacturing** which is readily obtainable with this method of layout.

The main advantages and disadvantages of the process method of layout, by departments, are summarized in the following tabulations.

Advantages of Process Layout.

1. Lower investment in machines because of less duplication. Only enough machines of each kind are necessary to handle normal maximum load, instead of one in each product line. Overtime hours usually will take care of overloads.
2. Machines can be kept busy most of the time, because the number of machines of each kind usually is held to the number needed for normal production.
3. Wide flexibility in getting work done. Possible to assign jobs to any machine in the same class available at the time.
4. Workers are more highly skilled because they must know how to run any machine—small or large—in the group, and how to set up work, perform special operations, gage the work, and qualify as mechanics instead of operatives.
5. Foremen and supervisors become skilled and efficient in the operation of their respective kinds of equipment and are able to direct the set-up and performance of all jobs done on this equipment.
6. Manufacturing costs can be held down. Labor costs may be higher per unit under peak loads, but will be less under low production, than on a product line. Unit overhead costs will be lower under moderate production. Hence total costs may be lower when the plant is not near peak capacity.
7. Failures of equipment do not hold up a succession of operations. Work is merely transferred to another machine, if available, or a slight change in scheduling is made if the job is "rush" and no machines are idle at the time.

Disadvantages of Process Layout.

1. No definite mechanical channels exist over which work must flow. More difficulty is experienced in routing and scheduling.
2. More material handling and higher cost of material handling results from the separation of operations and the greater distances over which work must travel. More hand labor is involved.
3. Careful attention is required for the coordination of work. Absence of a mechanical control over sequence means use of move orders and possible loss or delay of work because of travel between departments.
4. Total time of production is greater because of transportation and because work must be moved into a department in advance of need for it, in order not to hold up machines.
5. Large banks of work may pile up because of delivery considerably in advance of processing, hold up for inspection after processing, awaiting move men when released, and time and delays in transit.

6. Absence of compact production line layouts and usually greater spacing between units of equipment in separate departments, plus need for more aisles, elevators, etc., for transportation, means more floor area occupied per unit of product.
7. More inspections are needed, usually one after each operation, where work then goes next to another department, instead of one at end of each group of operations.
8. Far more complicated system of production control, and absence of visual control. Close check must be maintained on all operations on all parts, with many work orders, time tickets, inspection orders and more orders made out, followed up and posted to records. More accounting, and far higher clerical costs than when work travels along production lines.
9. More training needed to develop workers for the respective jobs. Training in craftsmanship often involved.

The **layout of an aircraft plant** shown in Fig. 22 indicates the arrangement of departments in this case to be essentially controlled by processes performed.

PRODUCT LAYOUT.—For product layout a well-standardized product and large quantities of the same product are generally necessary. In some instances a line of machines may be set up to produce a given order of a few parts, and then machines may be rearranged for the requirements of the next order. In general, product layout is best adapted to mass production industries. The automotive industry is an outstanding example of what may be done in production by straight-lining. But the principles of straight-lining can be, and have been, applied in many other industries.

In product layout of machines, all emphasis is placed on the product. The machines required in the processing of the product are brought together in one department and set up in accordance with the chosen sequence of operations. Thus, in machining the **case** for the 1939 Chevrolet **transmission,** all of the machines required were brought together in one department and located as shown in Fig. 23 (Millard, Dept. of Ind. Engr., Cornell Univ.). Rough castings for passenger car transmission case entered the line of operation at *E* and left a completely machined case ready for assembly at *L*. Since such a line is set up for a certain required production per hour, and the machine for each operation is selected with that requirement in mind, the product will flow smoothly along with little delay.

In the following tabulations the principal advantages and disadvantages of product layout are given. They are the opposite, respectively, of the disadvantages and advantages of process layout.

Advantages of Product Layout.

1. Flow of work is over direct mechanical routes, which cuts down delays in manufacturing.
2. Less material handling because of shorter travel of work over a succession of adjacent machines or work stations.
3. Close coordination of manufacturing because of the definite sequence of operations over adjacent machines. Less likelihood of loss of materials or delays in operations.
4. Less total time of production. Delays between machines avoided.

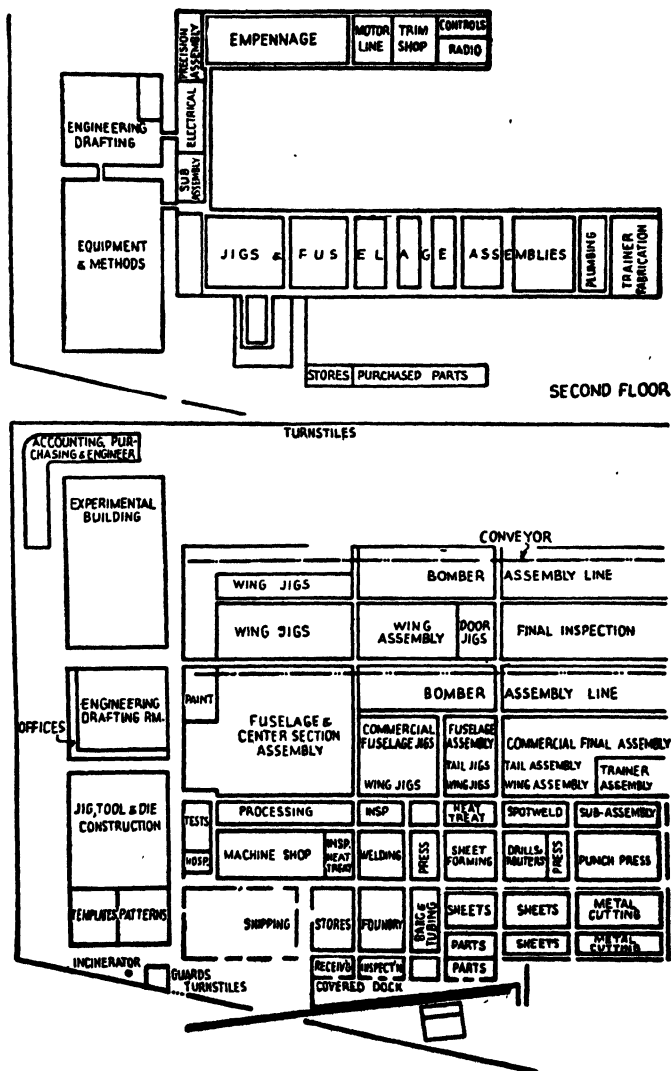



FIG. 22. Departmental Layout of an Aircraft Factory
(The Architectural Forum)

E. Rough castings enter line
L. Completely machined cases leave line
C. Machines for truck case only

X. Operator station
1, 2, 3, etc. Operation number for passenger car case
Roller conveyors

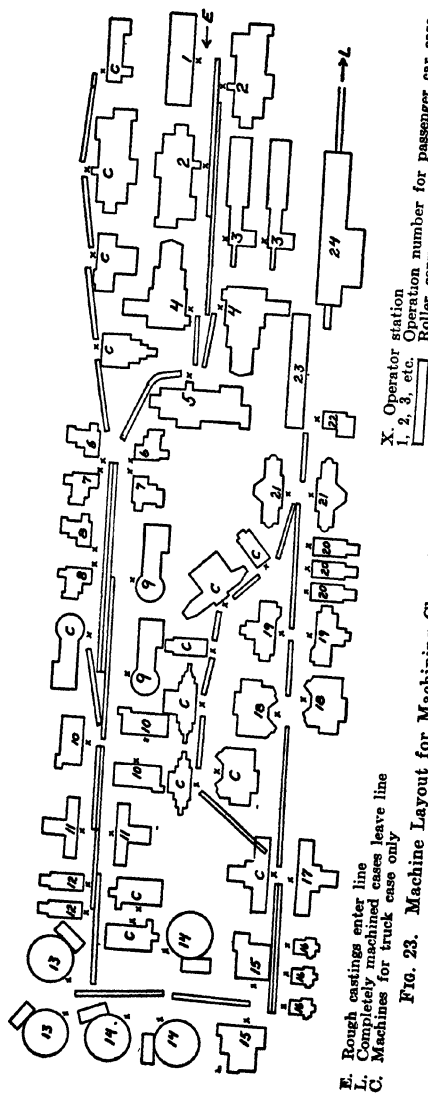



FIG. 23. Machine Layout for Machining Chevrolet Passenger Car and Truck Transmission Cases

5. Smaller quantities of work in process. Little banking of materials at individual operations and in transit between operations.
6. Smaller floor areas occupied per unit of product because of concentration of manufacturing.
7. Limited amount of inspection, perhaps only one before product goes on line, one after it comes off of line, and small amount of patrolling inspection in between.
8. Production control greatly simplified. Visual control replaces much of the paper work. Fewer forms and records used. Work checked on and off the production line. Few work orders, inspection tickets, time tickets, move orders, etc. Less accounting, and lower clerical costs.
9. It is easy to break in workers on any operation in the production line.

Disadvantages of Product Layout.

1. High investment in machines because of duplications in several production lines.
2. Considerable machine idlness if one or more production lines are running light or are down.
3. Less flexibility in getting work done, because jobs cannot be assigned to other similar machines, as in process layout.
4. Lower skill of workers. Each learns job at a specific machine or work station, which often consists of automatic equipment merely fed by operator.
5. Supervision not highly efficient. Supervisors regulate work over a series of different machines and do not become skilled in the work of any one kind of machine, involving knowledge of set-up, speeds, feeds, possible range of work, etc. However, since the machines are prepared for operation by skilled set-up men, supervision, even though it covers a series of different machines, may not unreasonably be expected to be as efficient as if covering only one kind.
6. Manufacturing costs may tend to be higher, even though labor costs per unit may be lower, because of the high factory overhead on production lines, especially large per unit when the lines are running light, or are occasionally idle.
7. Danger of shutdown of production line if one piece of equipment breaks or fails. Unless there are several machines of a kind, reserves of replacement equipment, or immediate emergency repairs, are necessary to keep work flowing.

Example of Change from Process to Product Layout.—Hart and Bangs (Straight-Line Production, Alexander Hamilton Inst., Rep. 532) reported the following illustration of a change from process layout to product layout. It concerns a common machine-made part, a shaft for a small rotating switch, shown in Fig. 24. Also shown in Fig. 24 is a list of 20 operations performed under the process method, and the simplified list of 11 operations under the product method. Improvements in manufacturing methods eliminate the sandblasting operation, several inspections, and a storing operation which is not required because the product is moved straight to assembly.

The report states: "The **process method involves 20 operations** ranging from 'Turn and thread teat end, and cut off,' to 'Assemble,' and in the performance of these operations the shaft wanders all over four stories of a five-story building." Fig. 25 shows the path taken by the part in moving through the plant by the functional method. The im-

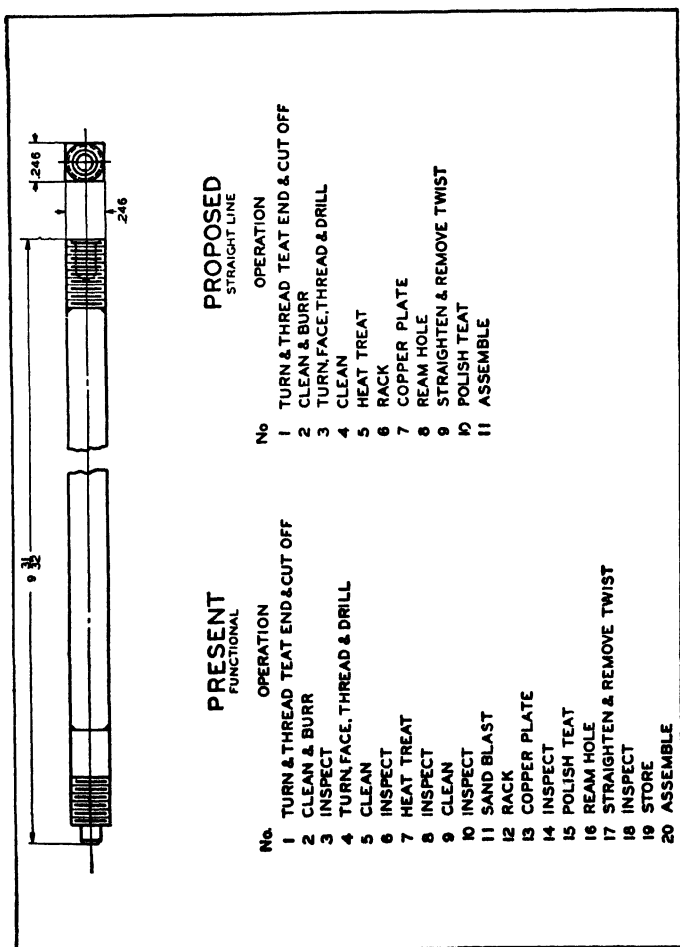



FIG. 24. Substitution of the Straight-Line Method for the Process Method of Manufacturing Reduced Production Operations on a Shaft from Twenty to Eleven

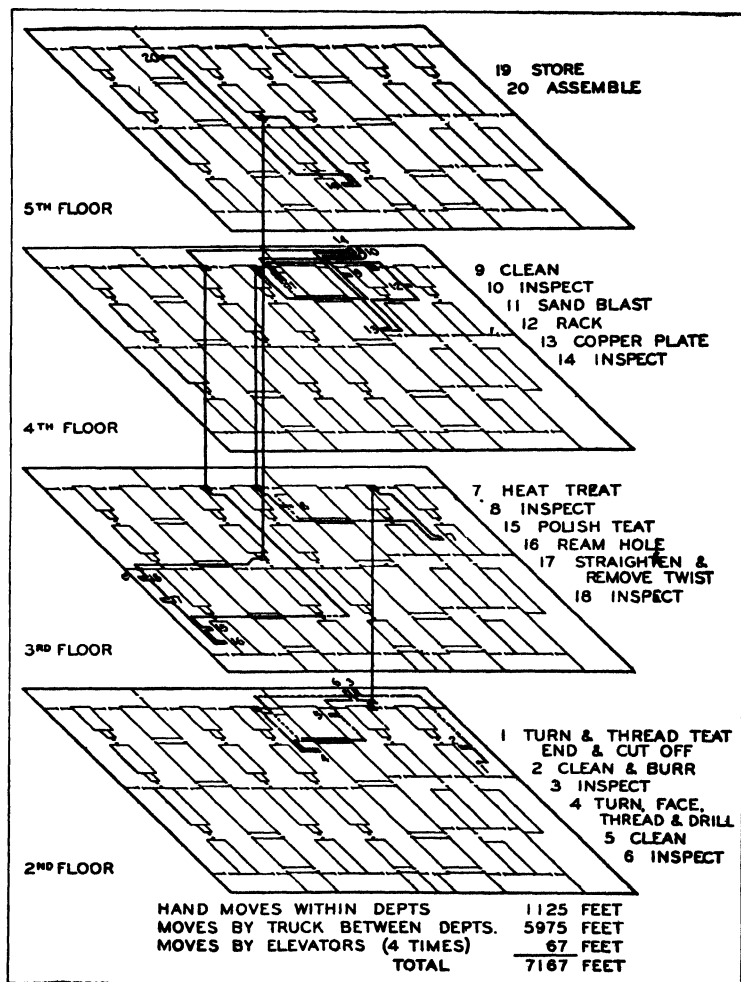



Fig. 25. Original Layout for Manufacture of a Shaft, on Four Floors of Plant

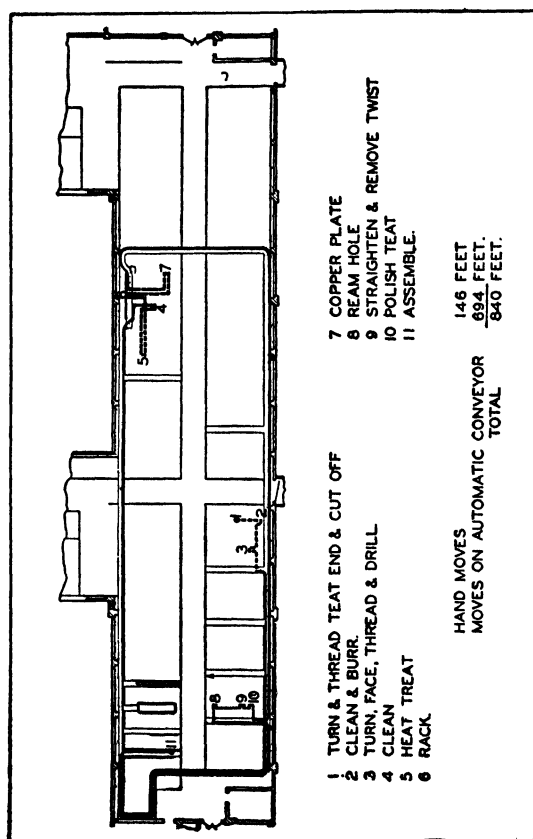



Fig. 26. In the Straight-Line Method of Manufacturing, the Path of the Shaft Was Reduced in Length, Simplified, and Limited to One Floor of the Plant

proved layout governed by the product is shown in Fig. 26, and **requires only 11 operations.** The physical savings effected by this change are shown in the following summary:

Factor	Process	Product
Number of operations	20	11
Distance traveled—conveyor or truck	5,975′	694′
Distance traveled—hand	1,125′	146′
Distance traveled—elevator	67′	0
Total distance traveled	7,167′	840′
Number of elevator moves	4	0
Production control sheets required annually	67,000	3,000
Manufacturing records required annually	4,900	250

For the complete special electric switch, the company concerned predicted the following savings as reported by Alexander Hamilton Institute in this same report on "Straight-Line Production":

Due to simplified control and storage, the value of the raw material investment is reduced 50%. Imposing as this amount may seem, the saving in the value of finished parts ready for assembly, commonly known as piece parts, is even greater. The piece parts investment is likely to reach large totals under the functional or process method, because, due to specialization, parts are many times completed in advance of assembly and, therefore, must be held in storerooms. In this example, a reduction in process inventory of 64% is expected by changing from the functional to the straight-line method.

New layouts will conserve 1,500 sq. ft. out of a total of 11,500 sq. ft. for a saving of 13%, and the manufacturing time interval of 43 days will be reduced to 5½ days, a reduction of 86%.

Operating labor (direct labor), the mark for most scientific management studies, is reduced but 12% as compared to indirect labor economies in inspection, production, and accounting, respectively, of 26%, 61%, and 47%. This condition shows in conclusive fashion that the straight-line method of manufacture really attacks and reduces the vital item of indirect labor, which is one of the principal components of overhead expense. Total reductions in direct and indirect labor are estimated at 16%.

While these savings were to some extent offset by increase in capital investment, they far overbalanced the increase and were easily justified.

Concerning the **cost of overhead for a machine tool plant,** arranged according to processes performed, Flanders (Mech. Eng., vol. 46) writes:

About four or five years ago, however, we lost the first keenness of our interest in direct labor and became concerned with the "overhead." With only a moderate increase in output, there had been a considerable increase in the number of foremen, functional and otherwise, and a great increase in the amount of clerical work they were called on to do. In fact, it had become necessary to provide many of them with clerks.

There was also a violent increase in the personnel of the cost and production offices. The attempt to control the whole organization from a central point led also to a flood of written orders and reports which was evidenced by the multitude, variety, and size of our printing bills.

It was possible, at any time and at any point in the shop, to make a rough estimate as to the percentage of the men in sight who were at that moment actually engaged in the process of profitable manufacture and to find that percentage quite unsatisfactory. (This visual estimate, it may be said, is quite a useful and revealing practice and every shop manager who has not acquired the habit should contract it at once. It should be made with a view to criticizing the management rather than the workers.)

Finally, the general statistics of the plant showed that the direct labor cost of the product was very small as had been hoped, and the material cost much higher, but the manufacturing overhead was the largest of all, so large that, with a moderate selling expense, the percentage of profit was somewhat precarious. The percentages were, in fact, such that if the item of direct labor cost had been completely eliminated there still would not have been any extraordinary profits at the selling prices prevailing.

RELATION OF MEN, MATERIALS, AND MACHINES.— Alford gives three ways in which men, materials, and machines may be brought together in manufacturing:

1. By stationing the worker at a given point or machine, and bringing to him the required materials and necessary tools. Continuous operations are an example of this kind of organization. The belt or chain assembly line for an automobile or other product affords an example.
2. By bringing the worker and machines to the material which has been placed in a fixed position in the shop. An example of this method is afforded by the manufacture of very large electric generators, where the machining is done by portable machine tools which are brought to the huge castings instead of the castings being moved to the machines. The governing reason for the adoption of this method is the size of the work.
3. Worker and material are brought to the machine. This is the common method in manufacturing. The machine is stationary, the material is mobile, and the worker can move from machine to machine as the needs of production require.

OPERATOR CYCLING OR MULTIPLE MACHINE OPERATION.—Where semi-automatic and automatic machines are in use, it is generally possible to assign one operator to more than one machine. After loading and starting one machine, the operator can move to a second or a third machine, or perhaps more, before the first finishes its operation and is ready to be unloaded. To prevent excessive walking by the operator, machines tended by one man should be placed adjacent to one another as much as possible, and materials handling equipment should be designed to bring the work in process close to the work station. This is readily accomplished with process layout where all machines are similar and where line flow is not maintained. A screw machine department, for instance, where machines are loaded at relatively long intervals offers a good illustration.

This principle of assigning more than one machine to a worker is somewhat more difficult to apply with product layout because of the need for maintaining line flow and the fact that an operator must run a number of different types of machines. Even here, however, as a general rule, it can be accomplished. Fig. 27 shows an old layout and an improved layout designed to use the operator's time more effectively. While idle machine time may be increased by thus grouping machines, if properly worked out it will be more than compensated for by savings in direct labor. The delays caused by machine idleness, adjustments or breakdowns, or difficulty with the material are classed under the term "machine interference."

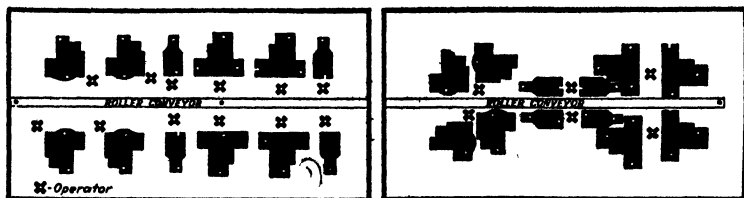



FIG. 27. Old and New Layout Showing How Machines Can Be Rearranged So One Man Can Operate More Than One Machine
(Fact. Mgt. & Maint.)

NUMBER OF MACHINES AN OPERATOR CAN TEND.— The number of machines an operator can tend depends upon the standard time for the operation, the hourly production required from the machine, and the coordinating of man and machine time. When machines are to be placed in a group, they should be located as near one another as possible to save walking time and effort of the operator. In a product layout this arrangement depends upon maintaining the

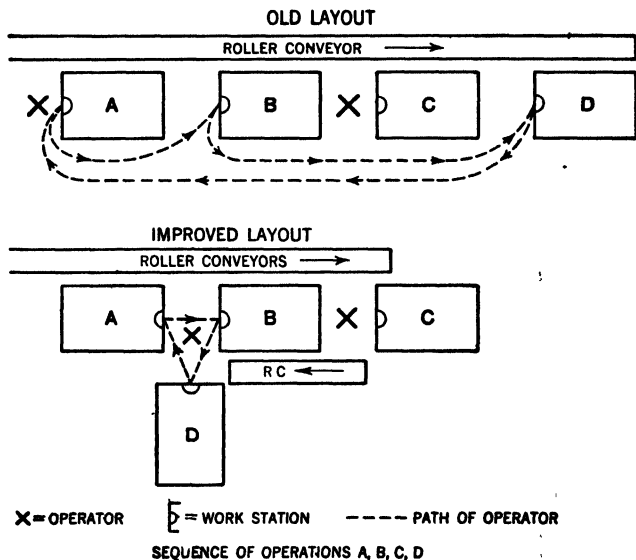



FIG. 28. Old and Improved Machine Layouts, Latter Designed to Lessen Walking Time and Effort in Operating or Tending Several Machines

line of flow without excessive travel of material. Bends or loops in the line often may bring the product back into an area through which it has already passed in the course of operations (see Fig. 28).

Figs. 29 and 30 show what was accomplished in the Cadillac Motor Car Co. plant by **study, timing, and grouping of operations.** Fig. 29 shows the original layout where the product was moved by tote box from operation to operation. Fig. 30 shows the improved layout designed to conserve space, time, effort, and cost. Material is moved from work station to work station by chute. Machines are grouped to use the operator's time most effectively. This fact is well illustrated by the loop bringing machine 10 adjacent to machine 6 for operation by one man. By this apparently random but nevertheless studied layout, work in process was substantially lessened, 17 men could do the work of 27, several machines were eliminated, floor space was cut 40%, and numerous indirect expenses were reduced.

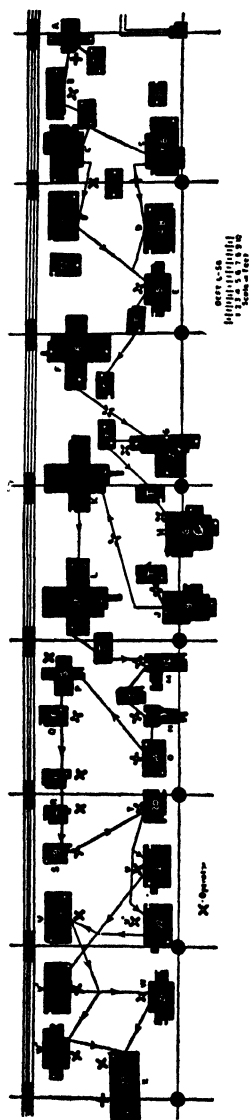



FIG. 29. Old Layout for a Department Machining a Piece Weighing 16 lb.
(Fact. Mgt. & Maint.)

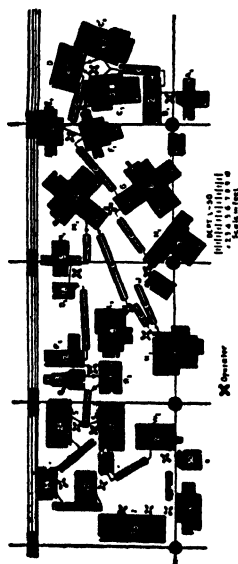



FIG. 30. Improved Layout of the Department in Fig. 29
(Fact. Mgt. & Maint.)

MACHINE BREAKDOWNS.—As machine breakdowns are inevitable, provision must be made to keep the maximum amount of plant working regardless of individual out-of-order machines. In process layout, operations of subsequent departments are not dependent solely upon flow of work in large volume along a definite production line under any one manufacturing order, or in successive lots, so a machine breakdown does not effect a general plant stoppage. Since similar machines are grouped together, urgent operations can be shifted readily to some other machine.

In product layout **a single machine breakdown will stop the entire line.** Two kinds of provisions are taken to minimize such plant tieup: (1) immediate replacement of the crippled machine, and (2) providing a bank of work ahead of each operator. The first of these procedures requires additional capital investment in machines; the second requires additional investment in work in process. The automobile industry, for the most part, replaces the crippled machine, or sets up a temporary machine through which it shunts the parts while the machine in line is being repaired. A decision as to which method to use must weigh the cost factors of one against those of the other. If a work bank is to be used it should be large enough to keep each operator busy for the length of time taken to make the average repair. If the machine is to be replaced, or temporary machines are to be set up, aisle space or crane service must be available.

Maintenance and machine repairs must also be kept in mind when positioning a machine so as not to have the parts of the machine which require normal maintenance and repair butted up against a wall, pillar, or other machine.

Auxiliary Factors in Layout

RELATION OF MATERIALS HANDLING EQUIPMENT TO PLANT LAYOUT.—Handling work in process is nonproductive in that it adds no value to the product. Handling should therefore be held to a practical minimum. In spite of its nonproductive character, estimates show that handling of materials represents, on the average, 22% of the cost of manufacturing. It is the greatest single item of labor cost.

Materials handling problems must be worked out coincident with other plant layout and machine layout problems. No one problem can be divorced from consideration of the others.

HANDLING DELIVERIES AND SHIPMENTS.—The receiving and shipping departments must generally provide for the handling of deliveries and shipments arriving and leaving by either trains or trucks, or both. These departments should be so located as to serve the entire plant. For heavy-product industries, railroad tracks are commonly laid directly into the manufacturing building for receipt and shipment of products. Such tracks should be laid flush with company streets and building floors. At the actual receiving and shipping points, a common practice is to lower the road or track level to bring the floor of the truck or freight car level with the building floor. Overhead traveling cranes can serve open or flat cars, but not box cars.

REQUIREMENTS FOR INDUSTRIAL TRUCK OR TRACTOR AND TRAILER HANDLING.—For long hauls of heavy products in the larger companies, railroad cars or motor trucks may be used, and well-laid-out tracks and smooth roadways are essential. For shorter hauls, such as to and from stockrooms and throughout manufacturing operations, the use of hand trucks or hand-operated, gasoline, or electric lift trucks with skid platforms or tote box is common. The fork truck for pallet handling is also widely employed, and the tractor-trailer method is used in many plants. Trailers, skids, or tote boxes often furnish convenient temporary storage devices where such are desired, and they are also increasingly used in shipping products from one plant to another. If industrial trucks or tractors and trailers

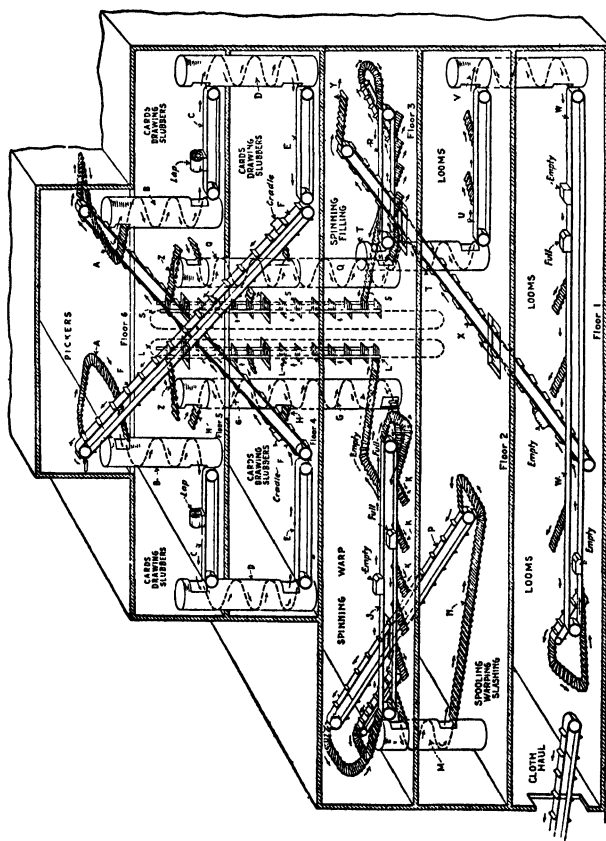



Fig. 31. Arrangement of Conveyors, Chutes, and Elevators in a Textile Mill (Robert T. Kent)

are widely used in multistory buildings, ramps to connect one floor with another are often provided to prevent dependence solely upon elevators with their attendant delays. Wide aisles and smooth, level, well-kept floors are necessary for industrial truck operation. Elevators are, however, indispensable as a material handling device in multistory buildings, especially for heavy articles, and their application is described later in this Section.

PROVISIONS FOR CONVEYOR HANDLING.—Where a **fixed route for flow of material** can be established, and where flow of material is continuous, a power-driven belt or roller conveyor, or overhead monorail conveyor may be used for either short or long distances. Liquids and powders can be moved in pipes by gravity or pressure under similar circumstances. When a product model change requires

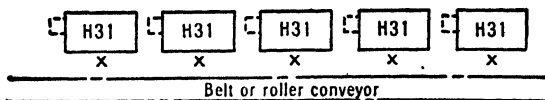



FIG. 32. Machines Laid Out Parallel to a Belt or Roller Conveyor. Material is moved to and from the machines by conveyor and no trucking aisle is needed. Operator turns through 180° to use the conveyor.

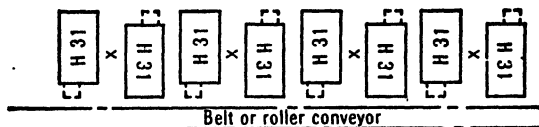



FIG. 33. Machines Laid Out Perpendicular to a Belt or Roller Conveyor. Operator turns through 90° to use the conveyor.

a relayout of the plant, the change may have to conform to the location of these conveyors if the cost to move them is too high. Short distance movement of material from operation to operation may be accomplished by roller conveyors or chutes placed at a sufficient incline to cause the product to be moved by gravity. In a multistory building where subsequent departments can be placed one under the other, this is one of the cheapest methods of moving the product. Fig. 31 is an illustration of this practice. For movement by gravity from station to station on one floor, operations should not be so far apart that the grade or pitch of the chute or conveyor will deliver the product at such a low level that the operator will have to stoop unduly, especially if the product is heavy.

From the standpoint of an operator at a machine receiving material from a conveyor, Barnes (Motion and Time Study)* presents the illustrations shown in Figs. 32 and 33. In the former figure the layout requires that the operators turn through 180° to get work from and put it back on the conveyor. One operator is required for each machine. In Fig. 33 the machines have been relocated so that the operators make only 90° turns, and each operator tends two machines.

* John Wiley & Sons, Inc.

ELEVATORS.—Nearly all elevators now are electric, and of traction type. Elevator engineering has kept well ahead of requirements, and elevator service may be provided for almost any need which is economical, adequate, and safe.

Present-day manufacturers equip elevators with starting and stopping devices which control the car, with microleveling equipment which automatically lines up the elevator floor with the building floor at each stop, and further safety devices which prevent elevator operation in an unsafe manner, and to a considerable extent make it "fool-proof" and accident-proof. The freight elevator is now frequently regarded as an item of materials handling equipment.

BUILDING FACTORS RELATED TO MATERIALS HANDLING.—The following is a schedule of building factors related to materials handling:

1. Long, narrow aisles should be widened at intervals to allow two of the largest trucks to pass.
2. Doors and aisles should be wide enough for easy passage of the largest loaded truck.
3. Doors with automatic door openers should have pull-rope switches on both sides in the path of travel.
4. Loading docks, elevators, aisle ends, and aisle intersections should be of ample width and clearance for right-angle turns of the largest loaded truck.
5. Elevators should be capable of handling the heaviest loaded truck used above the ground floor.
6. Automatic elevator signals and controls minimize truck waiting time and facilitate materials handling.
7. Where ramps are used hold the grades to a minimum.
8. Layout of storerooms should be so arranged that columns do not interfere with convenient materials and parts handling.

FLOORS.—Factory floors are important from the standpoint of traffic of workers, and transportation of materials, and also because of the weight of machinery and materials which they must support and the impacts and vibrations which they must be able to withstand without transmitting them to the operating equipment. Floors must be comfortable, safe, durable, and capable of withstanding the loads to which they are subjected. A properly treated **concrete floor,** sometimes with steel grating imbedded in it, has excellent wearing properties and will bear heavy loads, but it becomes uncomfortably hard to one who must stand on it for long periods. **Creosoted wood blocks** set on concrete make a good load-bearing floor, resistant to surface wear, and not uncomfortable to stand on. It is not recommended where water is continuously present, and care must be taken that the creosote or pitch filler does not damage the product. Where slippery conditions exist, floors of **"nonskid" metal sheets** can be used. Special conditions of noise, comfort, decoration, and acid resistance may dictate the use of terrazzo or ceramic tile, linoleum, rubber, cork, or asphalt mastic floors.

Floors should be marked off with broad lines of durable white paint to indicate the delimitation of work areas around machines and equipment so that materials, scrap, miscellaneous tools, and other items may be kept within the boundaries of the particular location. It is especially necessary to mark off aisles with white paint to keep traffic lanes open

and prevent accidents. Workers should not be allowed to operate in the aisles nor to place tote boxes or work so that they will project into the aisles where trucks may hit them or other workers may fall over them. Piling of materials so that they will fall into aisles or adjacent work areas should be prevented. The white lines may also mark off areas to allow for work projection, as on screw machines, or overtravel of a machine table, as on a planer. These precautions are matters of good plant layout and housekeeping.

For efficiency and safety in materials handling, floors should have a hard, smooth, long-wearing surface, and should be promptly repaired whenever damage or deterioration occurs.

POWER FOR MACHINES AND EQUIPMENT.—Application of power to equipment influences machine arrangement and location. To an increasing extent, machines are being equipped with individual motor drive. This fact not only simplifies machine installation but also allows equipment to be moved readily and set up in new locations, because each machine and its drive are moved as a unit, without any disturbance to the power sources. It is not uncommon, especially in plants with considerable product layout, for anywhere up to 50 or more machines, constituting perhaps a whole department, to be moved and set up in a new location, ready for operation, over a week-end. The machines are merely disconnected from power outlets, picked up by lift trucks or put on trucks by overhead cranes, transported to their new position, and plugged into a nearby outlet. Therefore, well-placed electrical outlets provide flexibility in layout. Such outlets, in fact, perhaps in multiple, should be provided on a planned basis, when the cable and wiring systems for power distribution are laid out and installed. They can be in the floor, on walls or columns, or along the ceiling. The expense of larger wires and a few extra outlets at the start saves extra costs for alterations when machine layout changes are made.

Many long-established plants, however, are committed to belt drives because of the presence of a high percentage of older equipment not supplied with motors. Even in newer installations, unless a high degree of flexibility is required, the use of one motor to drive several machines by a line shaft and belting is generally more economical. Flexibility can often be obtained, even with line shafting, by group drive, that is, the use of a short motor-driven line shaft with a counter shaft for each machine. To eliminate the hazard and objectionable appearance of overhead shafting, the shafting is sometimes placed in covered channels in the floor, or hung on the ceiling of the floor below, the machine being belted down rather than up. Expense of the channel and rigidity of the layout is a disadvantage of such an arrangement. The decision concerning the power supply to be used must be made by weighing economies in investment and use of power against disadvantages in production arrangement.

Location of Auxiliary Departments

GENERAL OFFICE.—In small and medium-sized plants, general offices and those for principal manufacturing executives, engineers, and the like, are located together at the main entrance to the plant. This arrangement provides maximum convenience for the public, and elim-

inates the presence of outsiders in plant or grounds. Location should be about equally available to various plant buildings and departments. In larger concerns a separate building and location for factory administration offices may be preferable in order to bring together various phases of factory management, afford closer contacts for executives both with each other and their work, and to provide a better work environment.

FACTORY OFFICE.—The factory office from which are coordinated the manufacturing procedures—production control and the like—should be located as close to actual work area as practical. Frequent personal communication with key men and personal observation of events is often desirable, hence the need for close proximity. But noise, dirt, and fumes from manufacturing must be excluded and a pleasant office atmosphere maintained. **Balconies or mezzanine** floors often provide ideal locations for factory offices.

RECEIVING AND SHIPPING DEPARTMENTS.—The location of receiving and shipping departments is often determined by the location of trackage or streets which must necessarily be utilized, allowing only limited flexibility in arrangements. Two departments adjacent or combined, as in Fig. 9, may be convenient and economical to operate. A shipping department located at one end of a plant and a receiving department at the other end is often an effective and possible arrangement. **Trackage alongside a plant** may suggest unloading near one end, and loading near the other. In these cases a double track with a crossover switch will provide extra room for car storage and permit switching of cars from or to either loading or unloading points without disturbing work at the other. Locations on upper floors, using direct or spiral chutes to loading platforms, are feasible. Spiral chutes can be used as a reservoir for accumulating boxed goods ready for cars or trucks. When receiving and shipping are accomplished with trucks, thought may need to be given to movement and volume of nearby street traffic, including pedestrians, boulevard stops, stoplights, and the like. Use of side streets is an aid in merging plant traffic with general movements without creating awkward and hazardous cross-currents. Solutions of placing of receiving and shipping and other auxiliary departments are to be found in the various examples of layout in this Section.

STOREROOMS.—Storerooms include those for raw materials, finished products, and for finished or partly finished parts in process. Size of plant and variety of manufacture influence considerably the degree of centralization of these areas.

Raw materials are usually located close to a receiving track or platform and adjacent to the manufacturing departments which will perform the initial operation on the material. Separate storerooms may be advisable for different classes of material as for paper, steel stocks, tool steel, and for paints, oils, and varnishes. Size of plant, location of departments, available trackage, and character of materials to be stored are determining factors. An outdoor yard storage is practical for materials not injured by weather or made more costly to handle or use as a consequence of freezing, becoming wet, or rusting. Materials light in weight, having special characteristics such as high value, requiring special handling, or used by one department only, may be stored in areas on upper floors close to points of use and under the control of the depart-

ment concerned. Preliminary cutting operations on stock are performed in many cases in storerooms, and articles are made available to operating departments in the desired sizes and quantities.

Intermediate storage of parts during the manufacturing process is logically adjacent or near to those departments which require the material. One storeroom can be used for different classes of material in various stages of manufacture. **Finished products** are usually stored near to shipping departments, and convenient for loading operations. The nature of some products may permit storage in upper stories of a plant, and gravity movements downward into cars or trucks. **Separate special stores** may be advisable for such items as stationery, costly materials, items which require particular air or light conditions, oils and other liquids, and materials for plant maintenance work.

TOOL CRIBS AND TOOLROOMS.—Tool cribs, in which tools, fixtures, dies, patterns, etc., are kept, should be located convenient to the manufacturing areas served. These tool cribs should include facilities for sharpening and repairing tools. A common practice is to have a central tool department where toolmaking, if any, is carried on, where expensive and less frequently used tools are kept, where major repairing is done, and tool records are kept. This central department is supplemented by a number of smaller tool cribs located about the plant where needed, for issuing tools to set-up men and workers.

POWERHOUSE.—The powerhouse or engine room will need to be located with reference to the fuel and the ash handling problems involved, and economy in distribution of its products in the form of power, compressed air, steam, hot water, etc. In some industries it is important, and in most industries it is preferable, that the powerhouse be so situated that prevailing winds carry smoke and dirt away from manufacturing operations.

LOCKER ROOMS, WASHROOMS, AND TOILETS.—Locker rooms preferably should be placed convenient and accessible for workers as they come to or quit work. If within departments, they should be near to time clocks—so that the fewest steps need be taken in ringing in and out—yet not so close as to cause crowding.

Since the location of locker rooms, washrooms, and toilets in departments may interfere with production arrangements, these facilities are often placed along with elevators and stairways in separate wings attached to a building, or in service towers. In one-story plants an arrangement similar to that in Fig. 9 may be provided, although outside entrances shown in this case are not usual. Another arrangement employed in one-story buildings with high ceilings, where only men work, is to place toilets on a mezzanine floor above the working area, reached by open iron stairways. In multistory buildings the placing of washrooms and toilets in the same location on all floors considerably reduces plumbing costs.

It is ordinarily not desirable to require workers to go from one building to another, or from one floor to another, to reach lockers, washrooms, and toilets. The time element enters, problems of supervision arise, and the accident hazard involved in using stairs is a real one, especially for women workers.

Regarding the time element, George Nelson (Albert Kahn, Inc.) says, "A simple calculation will show that in a single-story building housing 500 mechanics, if the toilets are misplaced by a distance of only 150 ft., the excess time involved in the workmen walking to and from the toilet rooms causes the manufacturer a loss of $5,250 annually." Where it seems advisable to have one washroom and toilet room serve two floors in a multistory building, it may be placed between floors where the workers need go down or up only half a flight of stairs. In any case, it is well to have **service facilities sufficiently decentralized** to avoid confusion and congestion in their use, especially at quitting time. The separation may be on a basis of departments, and for different classes of workers. Race differences in some cases necessitate separate arrangements and, if so, cost is considerable.

Rest rooms for women employees are preferably located separately from other units. They should be reasonably accessible, cheerful, provided with good air, and quiet.

Legal requirements and equipment and operating factors of sanitary facilities are covered later in this Section.

PERSONNEL DEPARTMENT.—The personnel department is preferably located on the ground floor convenient to the street the more readily to accommodate applicants, a large number of whom may be turned away immediately. They are thus saved much walking, and manufacturing processes are kept confidential, if that is desired. As the personnel department also keeps employee records, and especially if the dispensary is an integral part of the personnel department, the two should also be located convenient to the manufacturing area.

DISPENSARY.—The dispensary should be centrally located so as to be convenient to all and reached in a minimum of time in an emergency. It should further be accessible from the outside by driveway for ambulance service. As the essential location requirements of the dispensary and the personnel departments are much the same, the two are often found adjacent if not in one department. This arrangement permits the same person or persons to conduct employment physical examinations and attend to first-aid patients.

CAFETERIAS.—Plant restaurants and cafeterias should be centrally located, with a thought for convenience and accessibility in all weather, in order that maximum use may be made of them. Although not profit-making departments, they should contribute to the well-being of the worker, his personal feeling of satisfaction, and thus to production. In larger plants **table service** with linen tablecloths and napkins as well as cafeteria service are provided. As a supplement to a **central service** of this kind, branch cafeterias may be operated where hot foods, sandwiches, fruit, coffee, and milk are sold. Some workers prefer to eat lunch in or near their own departments, and possibly to add only a purchased drink or dessert to a lunch brought from home. Seating and table equipment may or may not be installed at these points.

OTHER DEPARTMENTS.—Like the departments just mentioned, other miscellaneous departments should be located with regard to the function they perform and their inherent requirements. **Drafting and photographing departments**, requiring high-grade light, are often given a northern exposure or placed on the top floor where skylights may be

used. They should be convenient to the engineering department, as should be the blueprint department.

As an important factor in labor maintenance, recreational facilities for employees should not be overlooked, but they may be located wherever space, convenience, and the nature of the sport dictate. Quoits can be set up in any yard, skating rinks made on flat-roof structures, and badminton courts set up on any idle floor area of suitable size. In large companies, ball fields, basketball courts, bowling alleys, etc., may be company-owned, but smaller companies can better arrange to use city facilities.

Typical Plant Layouts

A BOOKBINDING PLANT.—Fig. 34 shows a successful layout scheme for a bookbinding plant. An alternative plan would have been to have storage areas in the center. Flow of materials and work in process may be traced by reference to the index of operations and locations as given below:

Index of Operations and Locations

1. Carload receiving and shipping of print paper and waste paper
2. Print paper storage
3. Print paper cutting
4. Pressroom
5. Make-up room
6. Plate storage vault
7. Ink and roller storage
8. Press foremen's office
9. Printed storage
10. Folding (signatures)
11. Signature storage
12. Tipping
13. Gathering
14. Stitching
15. Smashing
16. Stitched storage
17. Trimming
18. Gilt edging
19. Rounding and backing
20. Super finishing
21. Hand supering
22. Cover stockroom
23. Cutting and trimming
24. Printing and embossing
25. Art department
26. Covering
27. Cover drying storage
28. Assembling and wrapping
29. Finished stock
30. Receiving and shipping room
31. L.C.L. receiving and shipping
32. Truck receiving and shipping
33. Waste paper baling
34. Waste paper storage
35. Coal storage
36. Repair shop
37. Lunchroom
38. General office
39. Men's locker room
40. Women's locker room
41. Men's toilets
42. Women's toilets

Manufacturing operations, their sequence, and the movement of work in process may be briefly summarized:

Print paper in sheets on lift truck skids is received by carloads at (1), stored at (2), cut and trimmed if necessary at (3), and delivered to the presses at (4) for two or more impressions.

Page forms or plates are stored in vault (6), assembled for press in make-up department (5), and delivered to presses (4).

Ink and rollers for presses are stored in (7) and press foremen's office (8) is used also for inspection of printed sheets.

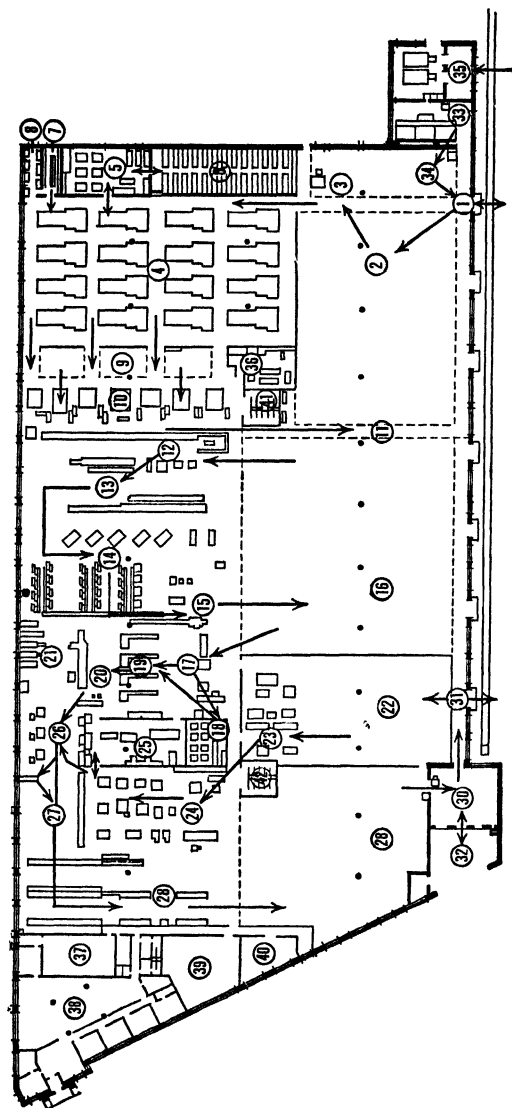



Fig. 34. Layout Plan for a Bookbinding Plant

Printed stock is delivered by electric truck to storage (9), then to folders (10), and folded signatures in bundles are stored at (11) until required for further process.

From (11) signatures are processed through tipping and stripping (12), gathered into volumes at (13), stitched into volumes at (14), smashed to close stitching at (15), and returned on skids by electric truck to storage (16).

Final binding begins from storage (16), to trimming (17), gilt edging if necessary at (18), to rounding and backing at (19), superlining at (20), and delivered to casing in machines at (26). Small orders are finished by hand at (21).

Covers are made from stock stored at (22), received by truck or carload at (32) and (31), cut at (23), ready for printing and embossing at (24), art work is done at (25), and they are delivered to casing-in machines at (26).

From casing-in at (26) the books are pressed and stored for drying of glue at (27), then inspected, wrapped, and assembled into sets at (28), stored in warehouse stock (29) to be shipped from (30) by truck or carloads at (32) and (31).

Waste paper from trimmers (17) is stored and baled by grades at (33), held for carload quantities at (34), and shipped at (1).

LAYOUT OF A MACHINE SHOP.—Figs. 35 and 36 show old and new layouts for a plant making governors and gas regulators. The crowded and congested condition of the old machine shop interfered with the use of lift trucks and platforms, causing unnecessary handling of materials by operators and consequent loss of time. More space was also needed for new products. Changes made were designed to provide improvement in the following particulars:

Raw materials received by trucks, taken to basement storage by elevator and to production by present or a new elevator, one at each end of storage room and convenient to departments requiring service.

Lathes and first operation machines in proper line for raw materials. Final operation machines, such as drills, mills, broach, etc., are located beyond lathes and adjacent to finished stock and valve fitting department for direct flow of parts.

Strategic location of valve fitting, testing, and heavy assembly work.

Finished stock room convenient to shop and to assembly.

Toolroom convenient to machine and brass shops.

A segregated brass department handy to finished stock, tools, and raw materials.

Assembly department located under much better light with room for expansion, and with chute and elevator for delivery of finished units to boxing and shipping department on lower floor.

Better space for lumber stores, box making, boxing, and shipping.

A central location for employees' locker and washroom, utilizing space too dark for good production, yet close to employee entrance.

A general loosening up of machine layout to allow room for use of lift trucks and platforms, which results in substantial saving in overhead and productive costs.

Ability to handle a substantial increase in production. Provision for expansion; machine shop to north, and assembly departments to southwest, allowing other departments to occupy more space as necessary.

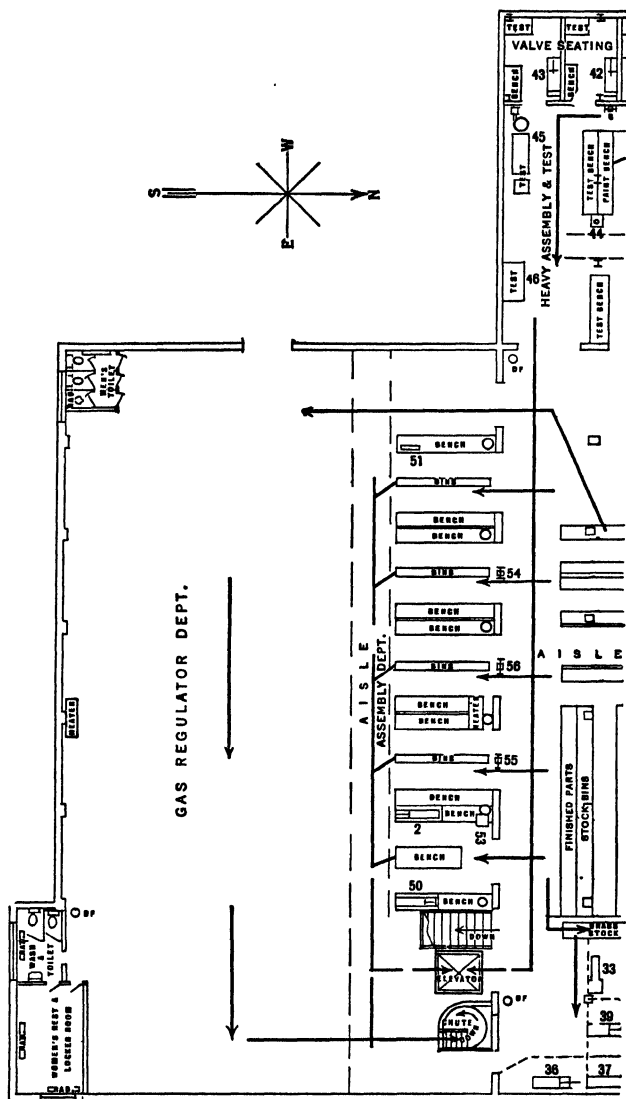
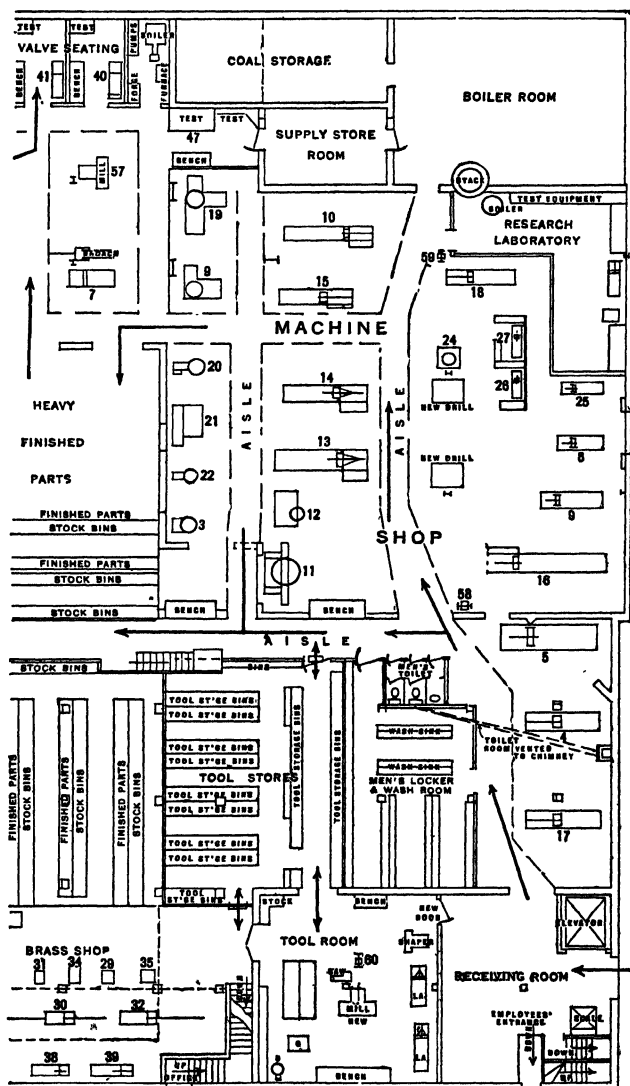



FIG. 35. Former Manufacturing Layout

for a Specialty Products Plant   (Frank D. Chase, Inc.)

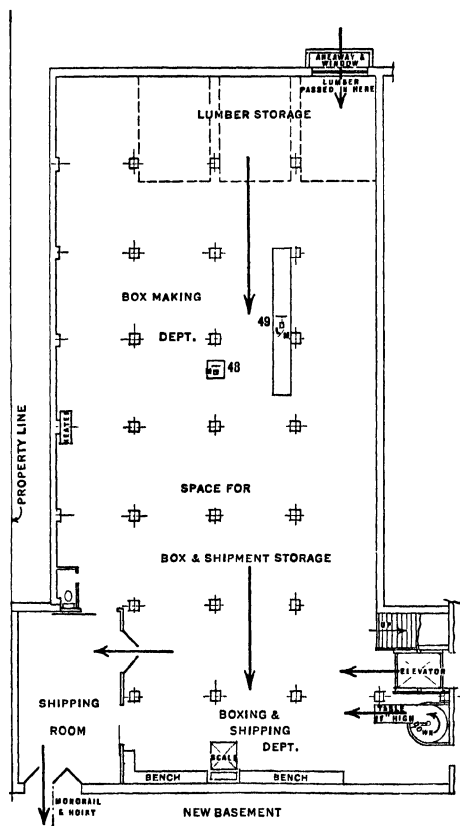
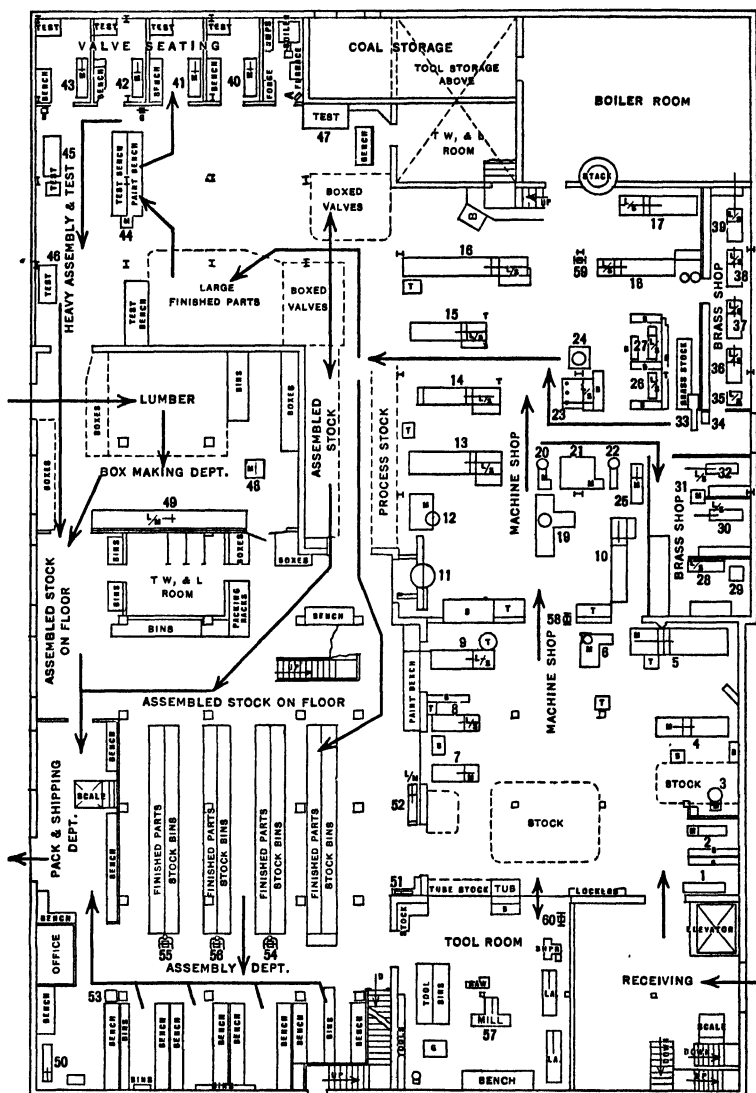



Fig. 36. New Manufacturing Layout

for a Specialty Products Plant (Frank D. Chase, Inc.)

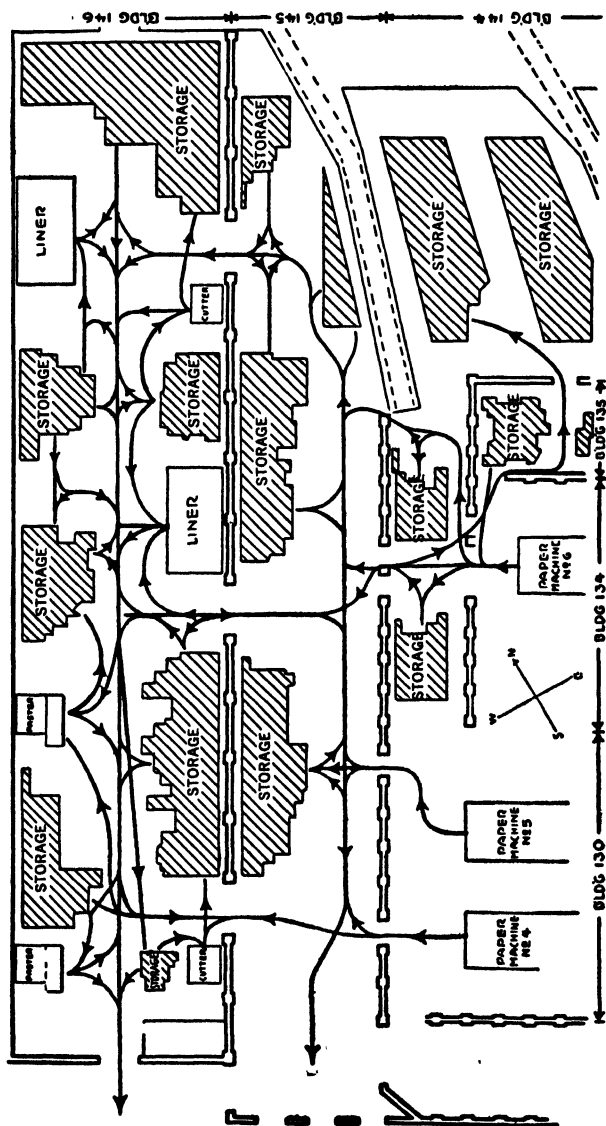



Fig. 37. Former Layout and Flow Chart of a Paper Processing Floor

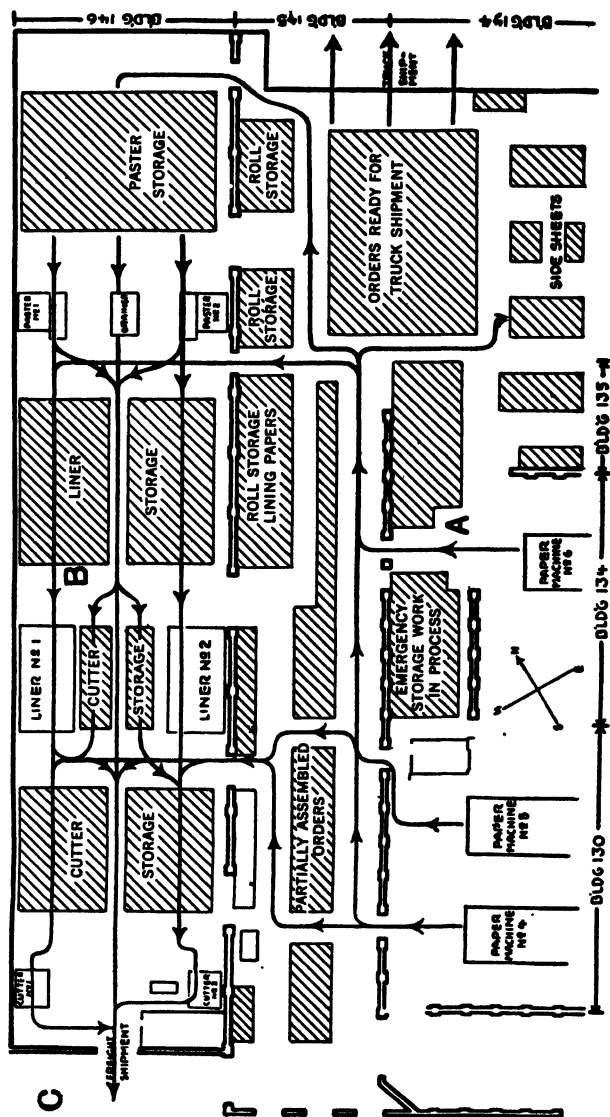



Fig. 38. Improved Layout and Flow Chart of the Paper Processing Floor in Fig. 37

ILLUSTRATION OF A PROBLEM IN LAYOUT.—The following illustration is taken from a study supplied by Robert H. Wells in connection with the rearrangement of certain departments in a paper mill.

1. A summary of the problem—the layout. Building 146 of the plant contained two pasting machines, two liners, two cutters, besides a grainer and an export press. The original arrangement is shown in Fig. 37.

Process. Paper came to this building from paper machines Nos. 4, 5, and 6. It was trucked by hand and unloaded on the floor at the most convenient points. Any one of, or any combination of, three operations (pasting, lining, cutting) might be required. Shipments were made by freight at the southwest end of the building, or by truck from the northeast end. The confusion in routing which resulted is shown by Fig. 37. Added to this was the fact that materials were stored on the floor, requiring that they be rehandled for each operation or to reach material further back in the storage area.

Improvements desired were:

1. Better routing of work in process.
2. Reduction of rehandling.
3. Reduction of handling expense.
4. Increased storage capacity.
5. Increased production capacity.

2. Solution of the problem—rearrangement of machines. As a first step in the reduction of handling costs the pasters, liners, and cutters were rearranged as shown in Fig. 38. Material from any paper machine is now brought by electric lift truck to a storage area at the right of the first process required. All materials now move from right to left as shown in Fig. 38, with the center aisle used when any operation is omitted.

All materials are kept on skid platforms, and material is individually handled only when going into and coming out of machines.

One man driving an electric lift truck handles all materials in Building 146. Two men with similar trucks bring materials from paper machines to process, storage, or shipping platforms; carry side sheets to storage and handle partially assembled or "hold" orders from storage to shipping.

By keeping material on skids, and by building a flooring over the railroad tracks in Shed 144, the amount of available storage space was increased approximately 15%.

Materials are now brought by truck to the cutters and pasters instead of the crews getting them. This has resulted in these crews increasing their production by 15% to 20%.

3. Cost of these changes. The complete cost of these changes is shown in the following:

Building changes	Flooring over railroad tracks—Building 144	$ 4,000
	3 new doorways—Buildings 145-146	500
	Removing walls and ceiling—Building 135	750
Moving machinery to new location	Pasters	400
	Liners	1,000
	Cutters	250
New equipment	500 skid platforms	6,000
	Electric industrial trucks	6,700
	Extra batteries and charging equipment for 24-hr. operation	1,500
Contingencies		500
Total cost		$21,600

4. Savings effected. The labor-saving from these changes was:

	Previous Number of Employees (Day Shift)	Number Required Under New Method	Number Released for Production Work
Foremen, clerks, and janitors...	6	4	2
Shipping crew	22	16 to 12	6 to 10
Stock tenders and loaders......	12	1	11
Cutters, pasters, liners, and finishers	26	22	4
Truck operators	0	3	3 add'l
Total day shift............	66	46 to 42	20 to 24
Total night shift..........	37	27	10
Total number of men saved...			30 to 34
Increase in production of cutters and pasters...........			15% to 20%

Calculation of annual savings effected:

30 men at $1,200..	$36,000
Increased production—3 cutter crews at $540...............	1,620
Increased production—3 paster crews at $810...............	2,430
Total annual savings......................................	$40,050

RELAYOUT FOR MANUFACTURE OF AN ELECTRICAL PRODUCT.—Oftentimes relayouts made better use of floor areas. This fact is illustrated in the case of Figs. 39 and 40 which show the original and the revised layout for the manufacture of an electrical product. Under the original layout, each operator to a large extent worked individually. In the revised layout conveyors were used to transport materials between successive operations. Work-stations were so arranged that operators performed only a few specialized functions, and thus were able to improve their efficiency while at the same time upgrading the quality of the product. The estimated increase in production amounted to 47% (Mallick, Plant Layout—A New Must for Industry, Westinghouse Elec. & Mfg. Co.).

Factory Building Services

PRINCIPAL FACTORY BUILDING SERVICES.—The major factory building services include provisions for electricity, steam, gas, and compressed air, factory lighting—both daylight and artificial—heating, ventilating, air conditioning, water, and other services within the plant. Most of these services in one way or another consist of fixed equipment, difficult and expensive to change. Further, operating costs are intimately dependent upon them. Hence, it is paramount that they be adequately planned for both present and anticipated requirements at the time they are installed. The importance of proper planning for these services and the technical knowledge required to design most of them makes it advisable to employ the services of a specialist in each field. It is intended here to present only the nature of some of their problems.

POWER-GENERATING EQUIPMENT.—The two most common sources of power in a plant are steam and electricity, although compressed air finds many applications and, of course, water power where

FIG. 39. Layout Used for Production of an Electrical Product, Where Each Operator Worked Almost Individually

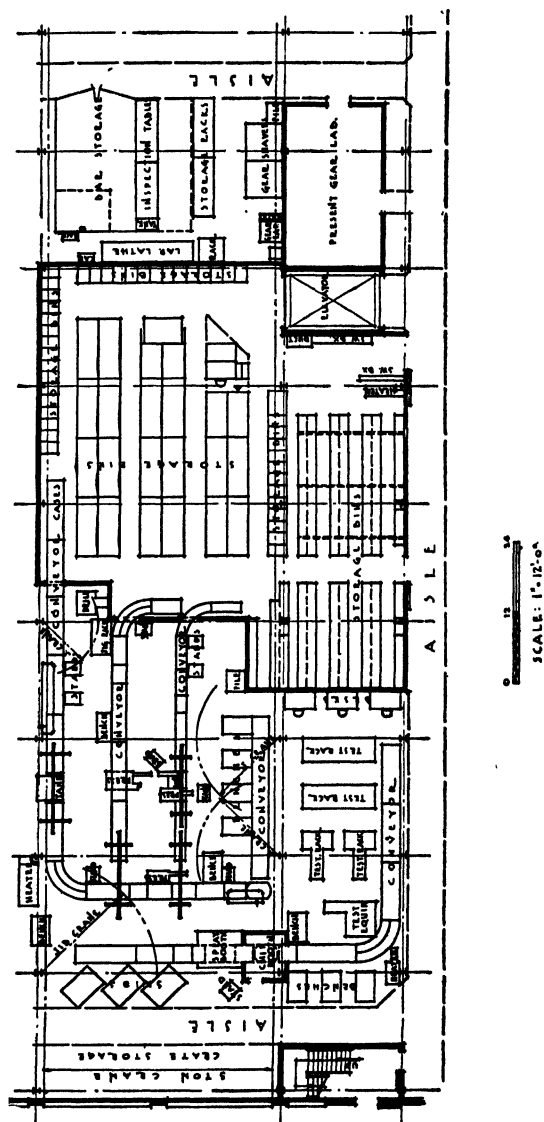



FIG. 40. Diagram of a Revised Layout of the Processing in Fig. 39, Utilizing Conveyors

it is available. Electricity and often steam may be either generated or purchased. What the policy in this regard should be can be determined only after a study by a competent power engineer of the individual circumstances involved. In general, a factory requiring a year-round supply of low-pressure steam for processing can frequently generate its own electricity more cheaply than it can be bought from the central station. If there is only a small or seasonal demand for exhaust steam, it is likely that it will be cheaper to buy electricity.

For large installations where both steam and electricity are needed constantly, steam boilers and turbo-generator sets are best suited. For smaller installations requiring both steam and electricity, steam boilers and either steam turbines or reciprocating steam engines are used. If steam is not required, the diesel-engine generating unit should be considered. Diesel fuel cost is lower than that for any other prime mover, efficiency is high for a wide range of ratings from 50 to several thousand horsepower and is nearly constant from full to half load, the engine can be started at a moment's notice, and there are no standby losses.

SERVICE DISTRIBUTION SYSTEMS.—Electricity, steam, gas, compressed air, drinking water, and toilet and wash water of suitable quality must be distributed through the plant to the most convenient places for their use, and factory wastes, odors, fumes, and dust must be removed.

Electricity serves two purposes in an industrial plant—light and power—and the distribution system for each purpose should be kept separate. Lighting circuits are generally 110/220-volt direct or single-phase alternating current, and power circuits 220-volt direct and 220- or 440-volt, three-phase alternating current. The usual voltage drop allowed between the source of power and the equipment is 2% to 4% for lighting circuits and 5% for power circuits. It is more economical to transmit current at high voltages if the distance is considerable, and to transform the voltage to low voltages close to point of use. In large area factories, it is sometimes feasible to locate step-down transformers on the roof near the center of the building. All conductors must be of ample size to minimize voltage drop and allow for load increases.

Many plants are now combining the lighting and power distribution circuits with a network system giving 220 nominal three-phase power supply and 110-volt lighting supply off the same lines with a four-wire system using star-connected secondaries of three transformers with a grounded common connection. This plan permits the use of small single-phase motors or light sockets on any machine tools and 220 three-phase power motors for the main motors with unit wiring for the machine tool itself, and is particularly valuable in connection with duct distribution systems.

Steam also serves two purposes in the average industrial plant—heat and power. Steam pressures are determined by the requirements of the process using it. Steam pipes must be of sufficient size to transmit the quantity and to withstand the pressures of the steam required. Principal losses from steam distribution result from inadequate or poorly installed piping systems, excessive radiation losses, and wastage caused by leaks. Lack of insulation, inefficient materials, poor application or deterioration of insulation may be the cause of much heat loss. Insulation of flanges, valves, and fittings, except for high temperature steam

lines, is of doubtful economy. For pipes, sewed-on canvas covering over insulation involves a higher first cost, but has the advantage of maintaining permanence of efficiency and appearance and lends itself to painting.

In the distribution of **gas and compressed air,** the principal considerations are **pressure, volume, and convenience of outlets.** Toilet and wash water should be clean and pure and of suitable pressure. Pipe sizes must be large enough to meet peak demands at shift changes without material effect in water pressure at faucets. An abundance of hot water should always be available and cold-water pipes should not be placed close to steam lines or other sources of heat.

ADVANTAGES OF GOOD ILLUMINATION.—Ease of seeing without eyestrain or tiring is fundamental to safe, efficient, economical operation in every factory. Ease of seeing is entirely dependent upon good illumination, whether natural or artificial. Advantages of good illumination are (Recommended Practice of Industrial Lighting—Illuminating Engineering Society):

1. Greater accuracy of workmanship, resulting in an improved quality of product with less spoilage and rework.
2. Increased production and decreased costs.
3. Better utilization of floor space.
4. More easily maintained cleanliness and neatness in the plant.
5. Greater ease of seeing, especially among older, experienced employees, thus making them more efficient.
6. Less eyestrain among employees.
7. Improved morale among employees, resulting in decreased labor turnover.
8. Fewer accidents.

ILLUMINATION AND SAFETY.—Not the least important among the advantages of good illumination is that of fewer accidents. As a result of extensive statistics collected over a period of many years, it is now generally accepted that poor lighting is the direct cause of 5% of all industrial accidents and a contributing cause in at least 20%. If

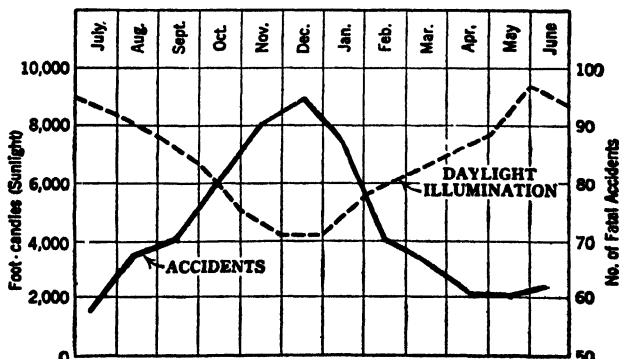



FIG. 41. Effect of Good Daylight in Reducing Accidents
(Westinghouse Elec. & Mfg. Co.)

improved lighting were to be effective in preventing, say, 15% of all industrial accidents, it would amount to tremendous savings in dollars and cents to say nothing of suffering and misery that would be avoided.

That there is a **close relationship between industrial accidents and light** is shown by Fig. 41, summarizing the results of a study of this subject. Fatal accidents definitely show an increase during months of poorer daylight illumination. The poorer illumination comes about because of the reduction in number of daylight hours, and the consequent twilight periods in the early morning and late afternoon, not because daylight intensities are lower during the middle of the day. The higher frequency of accidents would indicate (1) that a definite relationship does exist, and (2) that the level of artificial illumination has not as yet become adequate in supplementing or replacing daylight illumination in many plants, especially in stairways, passageways, and the lesser-used areas.

FACTORS OF GOOD ILLUMINATION.—Good illumination is made up of more than simply a proper level or quantity of illumination. Proper **quality**—which includes color of light, its direction, diffusion, steadiness, and absence of glare—as well as proper **quantity** is important. Consideration of the many factors involved in good illumination is a complex problem; hence, lighting installations should be designed by competent illuminating engineers.

QUALITY OF LIGHTING.—Color quality of light has been shown by studies to have little or no effect upon clearness or quickness of seeing as long as equal footcandles of illumination are provided. But for industries where color-matching is to be carried on, special light sources are highly important. A **footcandle** is the intensity of illumination produced on a surface by a standard candle at one foot distance. One footcandle of intensity requires a quantity of light equal to one **lumen** per square foot.

Diffusion, direction, and distribution of light may have a large effect upon the ease and accuracy of seeing. Diffusion is obtained by expanding the size of the light sources and by scattering the light in all directions, taking advantage of reflection from walls and ceilings. The result is a uniform light distribution, freedom from glare, and a softening or elimination of shadows. Direction of light is important if objectionable shadows are to be avoided. However, in accurate perception of three-dimensional figures, the presence of shadows obtained by directional lighting is desirable. This condition may be true for certain types of inspection. A reasonably uniform distribution of light is essential if **eye fatigue** is to be avoided. The eye should not be subjected to conditions requiring that it move from a low to a high level of illumination or vice versa. If supplementary illumination furnishes a high level of illumination on the work area, the surrounding general illumination should be at least one-tenth of the high value.

Glare is one of the most common faults to be found in lighting. Glare is any brightness within the field of vision of such a character as to cause discomfort, annoyance, interference with vision, or eye fatigue. If prolonged, glare may be a cause of nervousness, and in any case, it will result in reduced efficiency and increased accident hazard.

Glare may be either direct or reflected; one is as bad as the other. **Direct glare** is that which reaches the eye directly from a bright source

of light either natural or artificial. To reduce direct glare from artificial lighting, direct, general-lighting luminaires should be mounted at a sufficient height to keep them well above the normal line of vision. **Reflected glare** occurs when bright images of windows or of artificial sources are reflected into eyes from any reflecting surface. Reflected glare is frequently more annoying than direct glare because it is so close to the line of vision that the eye cannot avoid it.

Unsteady illumination can be very annoying and tiring. Flicker has been practically eliminated by use of 60-cycle current, and stroboscopic effect from fluorescent lighting may be practically overcome by the use of two-lamp auxiliaries. Daylight illumination is subject to wide hourly, daily, and seasonal variations, and short-time variations when a bright sun is temporarily clouded. Automatic devices to increase artificial illumination when daylight drops may be used to maintain a uniform level of illumination. In most instances, windows should be equipped with shades or Venetian blinds, which may be adjusted to compensate for changing exterior conditions. Any device for adjustment of natural lighting should be controlled by some specified individual.

QUANTITY OF LIGHT.—Quantity of light supplied from whatever the source, either natural or artificial, should be determined by the work to be done. In general, the more trying the seeing task, the higher the degree of accuracy or fineness of detail required, the greater should be the illumination. Investigations in field and laboratory have proved that as the illumination on the task is increased, the ease and speed with which the task can be accomplished are increased. These tests have not yet established an upper limit but the harmful effects of low footcandle values are well known.

The tables in the "Recommended Practice of Industrial Lighting," published by the Illuminating Engineering Society, give the **recommended minimum standards of illumination** for industrial interiors prepared from studies of specific industries or from current good practice. Measurements should be made at the point of—and in plane of—seeing, whether it be horizontal, vertical, or at some intermediate angle. Where there is no particular point of seeing, such as for general lighting in halls, storage areas, and the like, the readings should be made on a horizontal plane 30 in. above the floor. Values in these tables, it is important to note, are **minimum operating values.** When windows are clean and lamps and reflectors new and clean, higher values should be obtained. The minimum intensity recommended on any working plane is 10 footcandles.

DAYLIGHT LIGHTING.—Much of following information pertaining to daylight lighting in industrial interiors and the illustrations in Figs. 42–47 are from a report of cooperative research of the Detroit Steel Products Co. and the Department of Engineering Research, University of Michigan (Industrial Daylighting).

Good practice in daylight lighting now calls for intensities none of which fall below a **minimum of 10 footcandles** on the working plane and requires as uniform distribution of light as practical. Consequently, window and roof lighting should be designed with this value as a base. It should be noted that the 10 footcandles is a minimum which should

be obtained when the sun is completely hidden and with 6 months' dirt on the windows. In general, single-story industrial buildings should have a window area of at least 30% of the floor area. No maximum limit for good seeing has yet been found.

DAYLIGHT THROUGH SIDE WINDOWS.—If light comes from one side only, adequate daylight of 10 footcandles or more will be transmitted into the interior of a normal building for a distance equal to about twice the height of the windows. If light comes from two sides, adequate daylight of 10 footcandles or more will be transmitted into the building from each side for a distance equal to about three times height of each window. This fact limits to about 100 ft. the width of buildings dependent upon side windows for illumination. **Curves of the daylight intensity distribution** in one-story buildings with sidewall windows are shown in Fig. 42

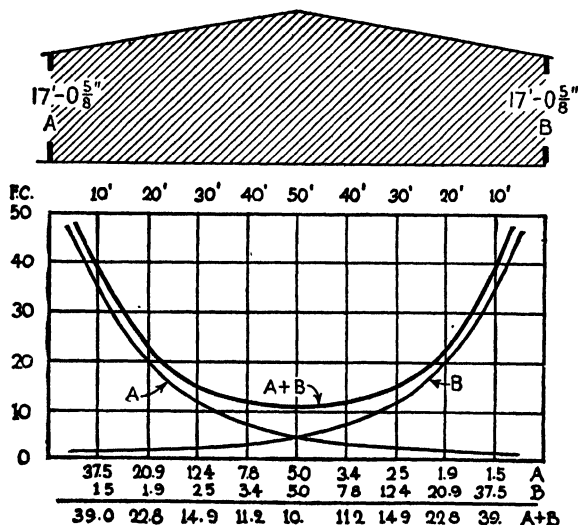



FIG. 42. Curves of Illumination Intensity from Side Windows

DAYLIGHT THROUGH SIDE AND MONITOR WINDOWS.—Monitors with vertical windows provide more light than comes from side windows alone. Monitors with sloping windows are next best. Skylights are least efficient. As a general rule, the best daylighting can be secured through a monitor with vertical windows designed with a monitor width equal to one-half the width of the building. Usually the width of a monitor should not be less than twice the height of its windows. Conversely, the height of a monitor should not be more than half its width. Increasing the height of a monitor, whether it be wide or narrow,

increases minimum illumination faster than it does maximum and thus helps to secure uniformity. Occasionally, sloping glass in a wide monitor helps to increase daylight at points of minimum illumination. Exceptionally uniform distribution of light can be obtained with a sawtooth roof facing north. The height of windows in sawtooth construction should be at least one-third the span. Curves of daylight distribution in a one-story building with two sidewall windows and monitor windows are shown in Fig. 43, and similar curves illustrating the effect of different monitor designs are shown in Fig. 44.

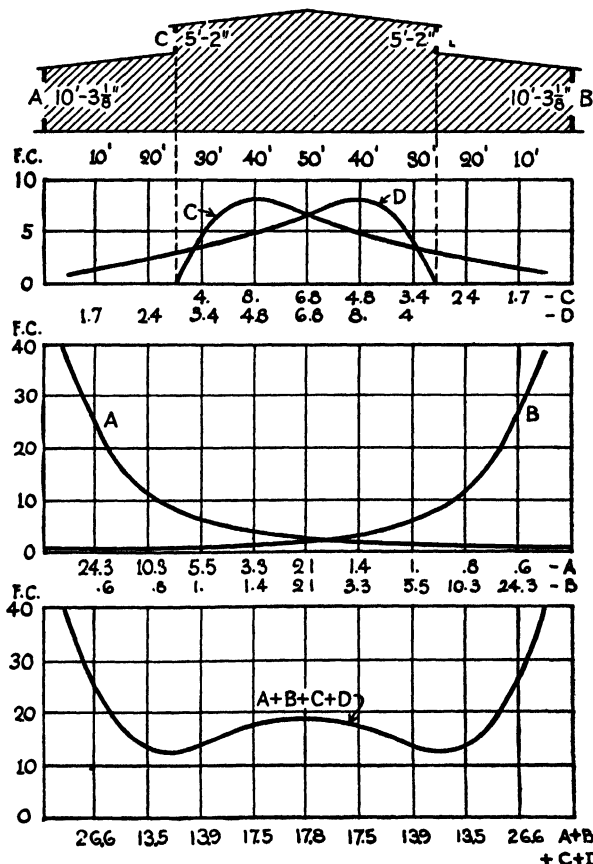



Fig. 43. Curves of Illumination Intensity Showing Effect of Monitor Windows

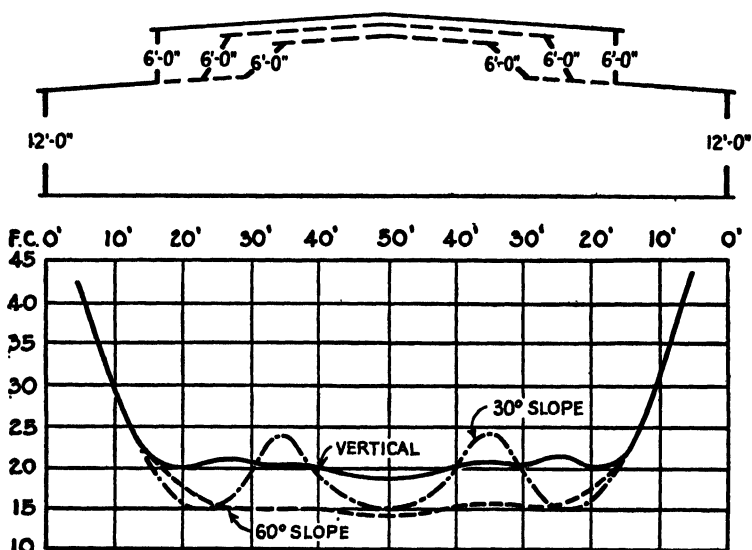



FIG. 44. Daylight Distribution in a One-story Building with Different Monitor Designs

TABLES OF DAYLIGHT INTENSITY.—The Detroit Steel Products Co. has developed the information in Figs. 45, 46, and 47 by which daylight intensity within a building may be figured. Fig. 45 gives footcandle values for sidewall windows of different heights; Fig. 46, values for vertical windows located at various heights above the working plane, as in a monitor; and Fig. 47, values for 30° sloping windows located at various heights above the working plane.

REFLECTING SURFACES.—On account of their reflection into the building of high light intensities, reflecting surfaces outside the building are as important as those inside. Faces of structures, walls of courts, and roofs of sawtooth buildings should be **finished in the lightest practical colors and so maintained.** The same course should be followed with interior surfaces. As between an interior painted black and an interior painted white, increase in light may easily be from 10% to 25%, and go as high as 100%, depending on width, height, and shape of building.

DIRT ON INDUSTRIAL WINDOWS.—Dirt on industrial windows is a serious detriment to proper daylight illumination. On the average, vertical windows lose 50% of their efficiency, windows sloping 30° lose 75% of their efficiency, and windows on a slope of 60° (average skylight) lose 83% of their efficiency, through a 6 months' accumulation of dirt. Accumulation of dirt on a window over a given length of time is

Ft. back from Window	3 High 5′ 2″	4 High 6′ 10″	5 High 8′ 6″	6 High 10′ 3″	7 High 11′ 11″	8 High 13′ 7″	9 High 15′ 4″	10 High 17′ 0″	11 High 18′ 9″	12 High 20′ 5″	13 High 22′ 2″	14 High 23′ 11″	15 High 25′ 7″
5	25.0	29.75	34.75	38.5	41.75	44.25	46.5	48.4	50.0	51.5	52.7	53.8	55.0
10	13.1	16.35	20.0	24.25	28.0	31.9	35.0	37.5	40.0	42.0	43.5	45.0	46.5
15	7.5	9.75	12.25	15.5	19.0	21.75	24.25	27.0	29.75	33.0	34.25	36.15	38.0
20	4.8	6.2	8.0	10.25	13.4	16.0	18.0	20.9	23.0	26.0	27.50	29.5	31.5
25	3.3	4.25	5.5	7.25	9.6	11.5	13.75	16.0	18.05	20.5	22.1	23.75	25.75
30	2.35	3.15	4.1	5.5	7.25	8.75	10.5	12.35	14.35	16.5	18.15	19.75	21.25
35	1.75	2.38	3.15	4.2	5.5	6.75	8.1	9.75	11.5	13.25	14.7	16.0	17.5
40	1.36	1.83	2.43	3.25	4.4	5.5	6.5	7.8	9.2	10.6	12.05	13.3	14.5
45	1.06	1.45	1.95	2.55	3.5	4.3	5.15	6.35	7.4	8.6	9.6	10.75	12.1
50	0.85	1.15	1.58	2.1	2.8	3.4	4.2	5.0	6.0	7.0	8.0	8.95	10.1
55	0.70	0.95	1.29	1.72	2.28	2.8	3.45	4.15	4.9	5.75	6.6	7.5	8.5
60	0.6	0.79	1.06	1.41	1.88	2.3	2.9	3.4	4.05	4.75	5.55	6.35	7.15
65	0.5	0.67	0.89	1.18	1.57	1.95	2.35	2.87	3.4	4.0	4.62	5.3	6.1
70	0.43	0.57	0.75	1.0	1.35	1.7	2.08	2.5	2.95	3.45	3.95	4.6	5.05
75	0.37	0.49	0.65	0.85	1 17	1.48	1.78	2.15	2.53	2.95	3.45	4.0	4.55
80	0.32	0.43	0.56	0.75	1.02	1.28	1.55	1.88	2.2	2.58	3.05	3.5	4.0
85	0.28	0.38	0.5	0.66	0.9	1.1	1.35	1.65	1.95	2.26	2.63	3.05	3.5
90	0.24	0.34	0.45	0.59	0.79	0.98	1.2	1.45	1.75	2.05	2.43	2.75	3.1
95	0.22	0.3	0.4	0.53	0.7	0 85	1.05	1.25	1.53	1.83	2.13	2.45	2.8
100	0.2	0.27	0.36	0.47	0.65	0.77	0.95	1.15	1.38	1.65	1.9	2.2	2.5
105	0.18	0.25	0.33	0.43	0.6	0.7	0.85	1.05	1.25	1.5	1.75	2.0	2.25
110	0.16	0.22	0.3	0.4	0.56	0.65	0.79	0.95	1.13	1.36	1.6	1.85	2.1
115	0.15	0.20	0.28	0.37	0.53	0.6	0.74	0.8	1.0	1.25	1.45	1.7	1.88
120	0.14	0.19	0.25	0.35	0.49	0.52	0.69	0.75	0.9	1.15	1.3	1.56	1.7
125	0.13	0.18	0.24	0.33	0 47	0.50	0.65	0.72	0.85	1.06	1.2	1.4	1.55
130	0.12	0.16	0.23	0.32	0.44	0.5	0.62	0.7	0.8	0.98	1.1	1.25	1.41
135	0.11	0.15	0.21	0.3	0.42	0.49	0.59	0.68	0.78	0.91	1.0	1.15	1.3
140	0.1	0.14	0.2	0.29	0.4	0.48	0.57	0.65	0.75	0.85	0.95	1.06	1.2

All glass 20″ high. All values figured for overcast sky and 6 months' dirt.

Fig. 45. Footcandles for Vertical Windows at Working Plane

about 75% on the inside and 25% on the outside. Windows should be washed at least twice a year and always should be washed in the fall so that all light possible will be admitted to the building during the darkest months of the year.

KIND OF GLASS TO BE USED.—The list in Fig. 48 gives the percentages of light transmitted through various kinds of glass.

With collection of 6 months' dirt, there is little advantage in any one of these glasses over any other. Clear glass and rough or hammered wire glass are much easier to clean, however, than either vertically or horizontally ribbed glass. Heat-ray restraining glasses are now widely used.

TRENDS IN DAYLIGHT ILLUMINATION.—During the First World War and for a decade thereafter there was a vogue for "daylight factories" with large window areas and sawtooth or monitor roofs. More recently, with the trend toward higher footcandle intensities and fluorescent lighting, increasing attention has been given to well-designed artificial illumination. Factors have been 24-hour-a-day operation, loss of light through large glass areas at night, lack of reflecting blind installa-

Feet Back From Window	15' Above Working Plane — Window Heights					25' Above Working Plane — Window Heights					35' Above Working Plane — Window Heights					45' Above Working Plane — Window Heights				
	3'6"	5'2"	6'10"	8'6"	10'3"	3'6"	5'2"	6'10"	8'6"	10'3"	3'6"	5'2"	6'10"	8'6"	10'3"	3'6"	5'2"	6'10"	8'6"	10'3"
5	3.0	4.0	5.1	6.0	6.65	1.15	1.5	1.8	2.1	2.5	0.6	0.85	1.1	1.35	1.6	0.43	0.85	1.4	1.95	2.9
10	5.8	7.4	9.8	11.2	12.0	2.2	3.0	3.55	4.3	4.7	1.25	1.85	2.25	2.85	3.6	1.2	1.7	2.4	3.25	4.15
15	6.6	8.0	10.6	12.8	13.8	2.95	4.4	5.15	6.5	7.1	1.9	2.7	3.3	4.3	5.2	1.7	2.45	3.3	4.05	5.1
20	6.0	7.65	9.8	12.05	13.6	3.5	5.1	6.25	7.75	8.95	2.38	3.3	4.0	5.4	6.6	2.25	3.2	4.0	4.75	5.75
25	5.1	6.8	8.5	10.6	12.2	3.8	5.2	6.6	8.3	9.75	2.73	3.6	4.5	5.9	7.25	2.65	3.8	4.55	5.35	6.25
30	4.3	5.8	7.45	9.2	10.65	3.6	5.0	6.05	8.35	10.00	2.85	3.7	4.6	6.0	7.5	2.85	4.15	4.9	5.75	6.55
35	3.6	4.8	6.35	7.8	9.05	3.4	4.6	6.15	7.75	9.15	2.7	3.55	4.5	5.9	7.45	2.75	3.95	4.85	5.65	6.4
40	3.05	4.0	5.4	6.6	7.8	3.1	4.15	5.5	6.95	8.1	2.45	3.35	4.3	5.75	7.1	2.55	3.7	4.6	5.45	6.15
45	2.5	3.4	4.45	5.5	6.55	2.8	3.7	4.9	6.2	7.25	2.25	3.05	4.0	5.3	6.8	2.35	3.45	4.35	5.2	5.85
50	2.05	2.8	3.7	4.65	5.6	2.55	3.25	4.35	5.5	6.5	2.08	2.8	3.65	4.9	6.4	2.15	3.15	4.0	4.9	5.5
55	1.65	2.4	3.0	3.85	4.75	2.25	2.9	3.85	4.9	5.8	1.9	2.55	3.3	4.45	5.85	2.0	2.85	3.7	4.5	5.25
60	1.25	2.0	2.5	3.25	4.0	2.0	2.55	3.4	4.35	5.15	1.73	2.3	3.0	4.05	5.4	1.85	2.6	3.45	4.15	4.9
65	1.1	1.65	2.1	2.75	3.4	1.75	2.3	3.05	3.85	4.55	1.55	2.1	2.7	3.7	4.8	1.65	2.35	3.15	3.9	4.6
70	0.9	1.4	1.8	2.4	2.95	1.5	2.05	2.7	3.35	4.0	1.4	1.9	2.4	3.35	4.25	1.5	2.15	2.9	3.6	4.3
75	0.75	1.15	1.5	2.05	2.5	1.35	1.85	2.4	3.0	3.5	1.25	1.75	2.18	3.0	3.85	1.35	1.95	2.65	3.35	4.05
80	0.6	1.0	1.3	1.8	2.2	1.2	1.6	2.15	2.65	3.1	1.15	1.58	2.0	2.7	3.45	1.2	1.8	2.4	3.1	3.8
85	0.5	0.85	1.15	1.55	2.0	1.05	1.45	1.9	2.35	2.75	1.06	1.43	1.83	2.4	3.1	1.12	1.65	2.23	2.85	3.55
90	0.45	0.75	1.0	1.35	1.75	0.9	1.25	1.65	2.05	2.45	1.0	1.3	1.68	2.2	2.75	1.03	1.5	2.08	2.65	3.3
95	0.43	0.6	0.9	1.2	1.55	0.8	1.1	1.45	1.8	2.2	0.93	1.2	1.53	2.0	2.5	0.95	1.38	1.95	2.45	3.05
100	0.4	0.55	0.8	1.08	1.4	0.65	0.9	1.2	1.5	1.95	0.9	1.13	1.4	1.83	2.33	0.88	1.25	1.85	2.3	2.85
105	0.35	0.5	0.7	0.9	1.25	0.5	0.75	1.0	1.35	1.75	0.81	1.05	1.3	1.68	2.1	0.80	1.18	1.7	2.15	2.65
110	0.3	0.45	0.55	0.8	1.1	0.4	0.6	0.85	1.16	1.55	0.76	1.0	1.24	1.55	1.98	0.75	1.1	1.58	2.05	2.98
115	0.28	0.39	0.54	0.7	0.98	0.37	0.54	0.73	1.02	1.35	0.73	0.96	1.18	1.45	1.85	0.70	1.03	1.45	1.99	2.3
120	0.25	0.36	0.48	0.63	0.87	0.32	0.46	0.63	0.89	1.2	0.69	0.92	1.14	1.38	1.73	0.67	0.97	1.4	1.83	2.15
125	0.23	0.32	0.43	0.55	0.78	0.27	0.39	0.55	0.76	1.1	0.67	0.88	1.09	1.30	1.60	0.64	0.92	1.3	1.73	2.08
130	0.21	0.29	0.39	0.5	0.7	0.24	0.35	0.47	0.67	0.98	0.64	0.85	1.05	1.25	1.52	0.60	0.87	1.18	1.61	1.93
135	0.2	0.27	0.35	0.45	0.63	0.21	0.30	0.41	0.58	0.86	0.62	0.82	1.02	1.20	1.43	0.59	0.82	1.10	1.53	1.84
140	0.19	0.25	0.32	0.41	0.58	0.19	0.27	0.37	0.51	0.76	0.60	0.8	1.0	1.19	1.36	0.57	0.79	1.05	1.45	1.75

All glass 20" high
3' 6"—2 panes high
5' 2"—3 panes high

6' 10"—4 panes high
8' 6"—5 panes high
10' 3"—6 panes high

All values figured for an overcast sky,
6 months' collection of dirt.

Fig. 46. Footcandles for Vertical Windows Above the Working Plane

Feet From Plane of Window	15' Above Working Plane				25' Above Working Plane				35' Above Working Plane				45' Above Working Plane			
	Window Heights				Window Heights				Window Heights				Window Heights			
	3' 0"	6' 0"	9' 0"	12' 0"	3' 0"	6' 0"	9' 0"	12' 0"	3' 0"	6' 0"	9' 0"	12' 0"	3' 0"	6' 0"	9' 0"	12' 0"
5	1.6	2.6	3.3	3.9	0.6	1.0	1.5	2.1	0.5	0.8	1.1	1.5	0.2	0.4	0.6	0.8
10	4.8	8.3	10.6	16.9	1.6	2.3	3.5	4.6	0.9	1.5	2.2	2.9	0.5	0.8	1.3	1.8
15	7.0	13.8	18.4	21.3	2.5	4.1	6.3	7.4	1.3	2.3	3.4	4.5	0.8	1.6	2.3	2.9
20	4.9	10.1	16.3	19.3	3.3	6.2	8.9	10.1	1.7	3.1	4.6	6.0	1.2	2.4	3.3	4.3
25	3.5	6.8	11.9	16.2	3.9	7.1	9.6	11.6	2.0	3.8	5.7	7.5	1.6	3.1	4.5	5.8
30	2.5	4.9	8.5	12.8	3.5	6.8	9.5	11.9	2.4	4.6	6.7	8.9	1.5	3.9	5.8	7.4
35	1.8	3.8	6.3	9.8	3.0	6.1	8.9	11.7	2.8	5.3	7.6	10.0	2.3	4.5	6.8	8.6
40	1.3	3.0	5.1	7.8	2.6	5.4	8.1	11.1	2.9	5.6	8.1	10.6	2.5	4.7	7.1	9.1
45	1.0	2.4	4.3	6.2	2.2	4.7	7.2	9.8	2.7	5.2	7.6	10.0	2.4	4.7	7.0	9.1
50	0.8	1.9	3.6	5.3	1.9	4.0	6.3	8.6	2.3	4.6	6.9	9.1	2.3	4.5	6.9	8.9
55	0.6	1.6	3.0	4.4	1.7	3.5	5.3	7.5	2.0	4.1	6.2	8.3	2.1	4.2	6.5	8.6
60	0.5	1.4	2.5	3.8	1.4	3.0	4.5	6.4	1.7	3.6	5.5	7.5	1.9	3.9	6.0	8.0
65	0.5	1.2	2.1	3.2	1.2	2.5	3.8	5.5	1.5	3.1	4.9	6.8	1.8	3.5	5.5	7.3
70	0.4	1.0	1.7	2.7	1.0	2.1	3.2	4.7	1.3	2.6	4.3	6.1	1.6	3.2	5.0	6.7
75	0.4	0.8	1.5	2.3	0.9	1.7	2.7	4.0	1.1	2.3	3.8	5.4	1.4	2.9	4.5	6.1
80	0.33	0.7	1.2	1.9	0.7	1.4	2.2	3.3	0.9	2.0	3.2	4.8	1.3	2.6	4.0	5.5
85	0.3	0.6	1.0	1.6	0.6	1.2	1.9	2.7	0.8	1.7	2.8	4.1	1.1	2.3	3.5	5.0
90	0.28	0.5	0.9	1.4	0.5	1.0	1.6	2.3	0.7	1.5	2.4	3.5	1.0	2.0	3.1	4.4
95	0.25	0.42	0.7	1.1	0.4	0.9	1.3	1.9	0.6	1.3	2.1	3.0	0.9	1.8	2.8	3.9
100	0.23	0.37	0.6	1.0	0.37	0.7	1.2	1.6	0.5	1.1	1.9	2.6	0.8	1.6	2.5	3.5
105	0.2	0.33	0.5	0.8	0.33	0.6	1.0	1.5	0.5	1.0	1.6	2.3	0.7	1.4	2.3	3.2
110	0.2	0.28	0.5	0.7	0.28	0.6	0.9	1.3	0.4	0.9	1.4	2.0	0.6	1.3	2.1	2.9
115	0.18	0.25	0.4	0.6	0.25	0.5	0.8	1.1	0.4	0.8	1.3	1.8	0.6	1.2	1.9	2.6
120	0.18	0.25	0.4	0.5	0.23	0.5	0.7	1.0	0.4	0.7	1.1	1.6	0.5	1.1	1.8	2.4
125	0.15	0.23	0.4	0.5	0.2	0.4	0.6	0.9	0.3	0.7	1.0	1.4	0.5	1.0	1.6	2.2
130	0.15	0.23	0.33	0.42	0.2	0.37	0.6	0.8	0.3	0.6	0.9	1.3	0.4	0.9	1.4	2.0
135	0.15	0.2	0.3	0.4	0.2	0.37	0.5	0.8	0.2	0.6	0.9	1.2	0.37	0.9	1.3	1.8
140	0.13	0.2	0.28	0.37	0.2	0.4	0.5	0.7	0.2	0.5	0.8	1.1	0.33	0.8	1.2	1.6

All values figured for an overcast sky, 6 months' collection of dirt

FIG. 47. Footcandles from 30° Sloping Windows Above Working Plane

Type of Glass	Light Transmission Factor in Per Cent When Clean
Clear sheet	82
Vertically ribbed	72
Horizontally ribbed	72
Rough or hammered wire	78

FIG. 48. Light Transmitted Through Various Kinds of Glass

tions to give good lighting of interior walls at night, and constant fluctuation of daylight intensities, which sometimes range from 15 footcandles to 200 footcandles.

ARTIFICIAL LIGHTING.—Artificial light may be classified as either general or supplementary. General lighting is that which provides the base or minimum quantity throughout a room. Supplementary lighting is that which is provided on a particular work area where illumination greater than that provided by general lighting is required.

General lighting is most often provided by fixtures placed 10 ft. or more above the work. It should furnish reasonably uniform light throughout the room at the working plane so that any part of the floor area may be used. This provision is particularly important for floors where machine layouts may be changed.

Supplementary lighting is generally provided by lamps directly at the workplaces. The lamp is hung directly over the machine or affixed to an arm for adjustment by the operator to meet his particular needs. Supplementary lighting may also be provided by spotlights arranged to raise the level of illumination on specified small areas. In designing supplementary lighting, care should be taken that too great a contrast does not exist between the work area and surroundings. In general, the ratio of maximum to minimum footcandles should not exceed 10 to 1. Care should also be taken to prevent glare, either direct or reflected, from a supplementary lighting fixture.

GENERAL LIGHTING SYSTEMS.—General lighting systems may be classified into the groups listed in Fig. 49, according to the amount of light received directly from the luminaire and indirectly by reflection from the ceiling. (See also Fig. 50.)

Classification	Approximate Distribution of Luminaire Output	
	Upward Per Cent	Downward Per Cent
Direct	0– 10	90–100
Semi-direct	10– 40	60– 90
General diffuse	40– 60	40– 60
Semi-indirect	60– 90	10– 40
Indirect	90–100	0– 10

FIG. 49. Distribution of Light Under Different Lighting Systems

DIRECT LIGHTING SYSTEMS.—In direct lighting, reflectors are employed to improve the distribution of light, diffuse direct rays from the lamp, and increase the apparent size of the source. They are least affected by dust and dirt, are not dependent upon wall and ceiling reflecting surfaces, and are most economical to install and operate, as little light is wasted, or lost by absorption. With direct lighting care must be taken to avoid glare, objectionable shadows, and too great light contrasts. RLM (Reflector Lamp Manufacturers Institute) reflectors are used widely for direct lighting in factories, either with a bowl-enameled lamp or with an opal-glass diffusing globe enclosing the lamp to decrease brightness and minimize glare, and a glassteel diffuser to distribute some light to walls and ceiling.

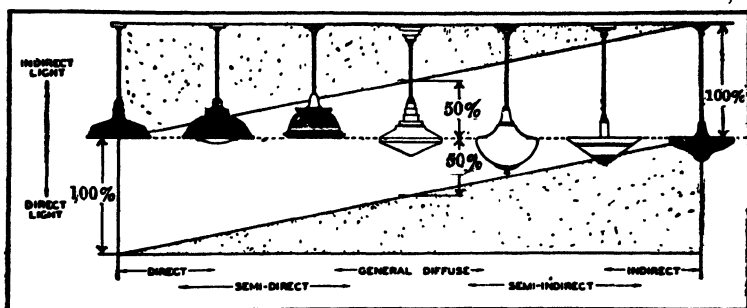



Fig. 50. General Classifications of Luminaires

SEMI-DIRECT LIGHTING.—The semi-direct lighting system is used to reduce some of the objectionable features of direct units while retaining their high efficiency. It is installed in corridors, stairways, washrooms, locker rooms, etc., where ceilings are low and the seeing task is relatively easy.

GENERAL DIFFUSE LIGHTING.—General diffuse lighting is probably the best compromise between direct and indirect lighting. The lighting fixture is generally made with an opal diffusing enclosing globe. It gives greater illumination per watt than the indirect type but shadows are more noticeable and glare may be troublesome. Such fixtures should be mounted fairly high for best results.

SEMI-INDIRECT LIGHTING.—For rooms with a high degree of ceiling reflection, semi-indirect lighting is well adapted. The light reaching the working area is well diffused, prominent shadows and glare are eliminated, but a higher wattage is required than for any direct luminaires for the same illumination.

INDIRECT LIGHTING SYSTEMS.—With indirect lighting, ceilings and walls are utilized for redirection and diffusion of all light emitted

by units. With the entire ceiling acting as a light source glare is reduced to a minimum and shadows are eliminated, but illumination of other than horizontal planes is more difficult. Naturally the cost of operation is greater because of the light lost by absorption and the greater effect of dust accumulations on this type of fixture. Where vapors or fumes are present, or the color of materials worked upon absorbs light readily, or reflecting surfaces are lacking, indirect lighting will not prove practical. For tasks which require perception of three dimensions shadows are needed, especially when contrast between the object and its background is slight, as in typesetting. Direct light is best for work of this kind.

FLUORESCENT LIGHTING.—Fluorescent lighting is a method of obtaining visible light from fluorescent coatings known as phosphors. These substances have the property of converting to visible light the short wave length radiant energy of a gaseous discharge. This method is in contrast to incandescent lighting, in which an element is heated to a point where it gives off visible light.

Some **properties** of fluorescent lights are of distinct advantage in industrial applications.

1. They give the closest approximation to daylight of any practical high-efficiency light source.
2. White and daylight fluorescent lamps are about three times as efficient as incandescent lamps.
3. By use of different phosphors, colored lights can be obtained at high efficiencies; for blues and greens, the ratio to incandescent lamp efficiencies may be as high as 50–100 to 1.
4. Because of their higher efficiency, fluorescent lamps generate less total heat than incandescent lamps giving the same illumination. Further, only about one-half of the heat is radiant, while practically all heat is radiant in incandescent lamps. This factor is important in showcases and in localized lighting for assembly and similar operations.
5. Fluorescent lamps are inherently a diffuse source of light of low brightness.
6. The tubular shape—approximately 1 to 2 in. in diameter, 18 to 48 in. long—is well suited to many applications.

The **principal drawbacks to the use of fluorescent lights** are: (1) first cost, which is higher than for incandescent lamps; (2) shortened life by repeated starts; (3) stroboscopic effect from a one-lamp unit may be objectionable if relatively fast movement is to be illuminated. Any gaseous-discharge lamp on alternating current gives off an intermittent light. With 60-cycle current the periodicity of intermittence is too fast for the eye to follow directly, but moving parts will be lighted in some locations and not in others and so appear to move in jerks or at speeds other than true speeds. This appearance is known as stroboscopic effect. While the phosphors of daylight fluorescent lamps have some carryover of illumination during the "off" period, this carryover is not great enough to eliminate entirely the objectionable effect. Stroboscopic effect may be greatly lessened by a two-lamp unit in which a condenser throws the current through one lamp almost 90° out of phase, or it may be practically eliminated by a three-lamp unit and three-phase current, one lamp across each of the three phases. (4) The power factor of a single-lamp

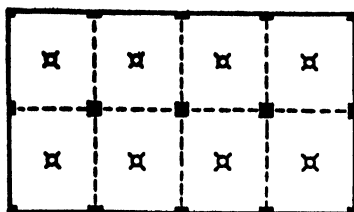
unit is approximately 60%, but can be improved by condensers of appropriate size across the usual type of reactor control. Most modern fluorescent fixtures are of a type of high power factor, as high as 90%.

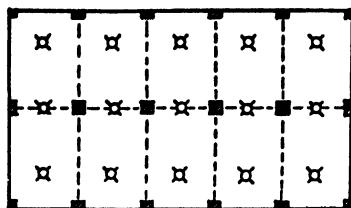
MERCURY VAPOR LAMPS.—For general illumination, the mercury vapor lamp has often been used for industrial lighting. It is an electric discharge lamp producing spectral lines characteristic of mercury vapor in the yellow-green area, a region of high response for the human eye and thus one of high luminous efficiency. Since mercury vapor light approaches a monochromatic light, some objection to its use results. It is commonly used in combination with incandescent lighting, about equal amounts of each being satisfactory to overcome objection to the yellow-green monochromatic light.

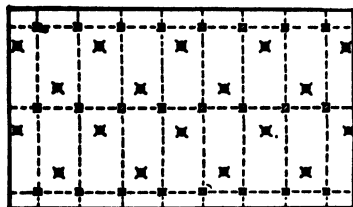
INTERIOR LIGHTING DESIGN.—Design of lighting for any given application should be carefully planned by a trained illuminating engineer. To give some understanding of the factors involved a simplified method of lighting design is outlined. This method is discussed in detail in "Artificial Light and Its Application" (Westinghouse Lamp Division, Westinghouse Elec. & Mfg. Co.). (Figs. 50–55.) The outline of the procedure follows:

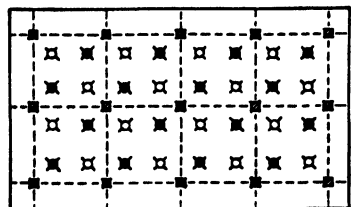
1. Decide upon the spacing of lighting units.
2. Obtain the room factor.
3. Select the footcandles required.
4. Determine the wattage of lamp required.
5. Figure the required wire capacity.

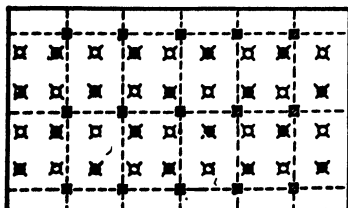
SPACING OF UNITS.—This problem involves the mounting height, light distribution, and structural details. Mounting height is limited by headroom and glare at one extreme and ceiling height at the other. In general, the spacing should not exceed the mounting height. Spacing is not so much influenced by size or type of lamp used as by the luminaire. For indirect lighting the spacing may be as much as one and one-half times the mounting height. For direct lighting, spacing should be less than the mounting height. Mounting height also affects shadows and may require change for that reason. **Structural arrangement of bays,** divided by columns, beams, or ceiling ornamentation, will generally call for a symmetrical arrangement of fixtures. Fig. 51 shows common arrangements of fixtures.

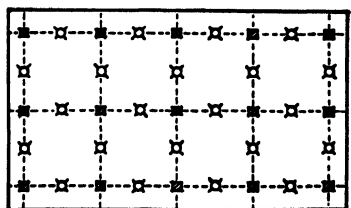
ROOM FACTOR.—Room proportions, reflection factors, and type of lighting equipment must be considered in designing a system of artificial illumination. Room proportions influence the amount of light absorbed by the walls, which does not reach the work area. Room width is classified as being approximately equal to, or two, three, or four times the ceiling height. The amount of light reflected from the walls and ceiling has a direct effect upon intensity of illumination. The color of such reflecting surfaces is classified as either light, medium, or dark. Such a classification may be obtained from Fig. 52. Next, the type of lighting equipment is determined and classified as direct, semi-direct, semi-indirect, or indirect. With this information available, the room factor —A, B, C, D, or E—may be obtained from Fig. 53.

1 – One per Bay

Usable where one side of the square is approximately equal to the mounting height.

2 – Two per Bay

Usable only where the space between columns will remain permanently open.

3 – One per Bay – Staggered

Although this arrangement of units is not symmetrical within the individual bays, it results in a symmetrical arrangement with respect to the entire room.

4 – Two or Four per Bay

The initial installation may consist of four units per bay, or two units with later addition of two more per bay to meet changed requirements.

5 – Three per Two Bays

If only the units indicated by black symbols are used, an average of three for two bays is obtained.

6 – Average of Two per Bay

An additional unit in the center of the bay may be installed later if more light is needed to meet changed requirements.

Fig. 51. Typical Artificial Lighting Layouts for Various Structural Arrangements

SURFACE	CLASS	COLOR	LIGHT REFLECTED PER CENT
Paint	Light	White	81
Paint		Ivory	79
Paint		Cream	74
Caen Stone		Cream	69
Paint	Medium	Buff	63
Paint		Light Green	63
Paint		Light Gray	58
Caen Stone		Gray	56
Paint	Dark	Tan	48
Paint		Dark Gray	26
Paint		Olive Green	17
Paint		Light Oak	32
Paint		Dark Oak	13
Paint		Mahogany	8
Cement		Natural	25
Brick		Red	13

Paint manufacturers' reflection values differ for similar colors, but the above table gives some idea of the colors in these three classifications and of the average reflecting qualities.

FIG. 52. Form Showing Per Cent of Light Reflected from Typical Walls and Ceilings

ROOM FACTOR						
PROPORTIONS OF ROOM	COLOR OF CEILING AND UPPER SIDEWALLS	DIRECT LIGHTING		SEMI-DIRECT LIGHTING	SEMI-INDIRECT LIGHTING	INDIRECT LIGHTING
		DISTRI-BUTING *	CONCEN-TRATING **			
WIDTH APPROXIMATELY FOUR OR MORE TIMES CEILING HEIGHT	LIGHT	A	A	C	C	C
	MEDIUM	A	A	C	D	D
	DARK	A	A	D	D	E
WIDTH APPROXIMATELY TWICE CEILING HEIGHT	LIGHT	B	A	C	C	D
	MEDIUM	B	B	D	D	D
	DARK	B	B	D	E	—
WIDTH APPROXIMATELY EQUAL TO CEILING HEIGHT	LIGHT	C	B	D	D	D
	MEDIUM	C	B	E	E	E
	DARK	C	B	E	—	—

* RLM Dome, Glassteel Diffuser, and Fluorescent Lamp Units
** High Mounting Reflector, Deep Bowl Reflectors

FIG. 53. Room Factor for Artificial Lighting

The values in this table have been calculated using the following data

Reflector efficiency (white bowl lamp) 66 %
Allowance for depreciation 30 to 40 %

These data apply to R.L.M. Dome reflectors equipped with white bowl Mazda lamps or slightly etched glass cover plate or glass ring when used with High Intensity Mercury Vapor Lamp. For clear or inside frosted Mazda lamps increase the average foot-candle values 10%

Typical distribution curve for R.L.M. Dome Reflector

Wherever possible mount the units 12 feet high to minimize glare

Minimum Mounting Height (Feet)	Approximate Luminaire Spacing (Feet)	Floor Area per Outlet (Sq Feet)	Room Factor*	Average Foot Candles: Mazda Lamps 100 Watt	150 Watt	200 Watt	300 Watt	500 Watt	750 Watt	1000 Watt	1500 Watt	Mercury Lamps 250 Watt	400 Watt
8	8 x 8	60-70	A	8.5-12	15-19	21-27	35-44	56-75				42-56	
			B	6.5-8.5	11-15	16-21	26-35	43-56				32-42	
			C	5.0-6.5	8.5-11	12-16	19-26	33-43				25-32	
8½	9 x 9	70-90	A	7.5-10	12-17	17-23	27-38	47-65				35-48	
			B	5.5-7.5	8.5-12	13-17	20-27	35-47				26-35	
			C	4.0-5.5	6.5-8.5	9.5-13	15-20	26-35				19-26	
9½	10 x 10	90-110	A	6-8	10-13	13-18	22-30	35-50	52-73			26-37	57-80
			B	4.5-6.0	7.5-10	10-13	16-22	27-35	40-52			20-26	44-57
			C	3.5-4.5	5.5-7.5	7.5-10	12-16	21-27	31-40			16-20	34-44
10½	11 x 11	110-130	A	5.0-6.5	8-11	11-15	18-24	30-41	44-60			22-31	48-66
			B	4-5	6-8	8.5-11	13-18	23-30	34-44			17-22	37-48
			C	3-4	4.5-6.0	6.5-8.5	10-13	18-23	26-34			13-17	29-37
11	12 x 12	130-150	A	4.5-5.5	7-9	10-13	16-20	26-35	38-50	55-72		19-26	42-55
			B	3.5-4.5	5.5-7.0	7.5-10	12-16	20-26	29-38	42-55		15-19	32-42
			C	2.5-3.5	4.0-5.5	5.5-7.5	9-12	15-20	22-29	32-42		11-15	24-32
11½	13 x 13	150-180	A		6-8	8-11	13-18	22-30	33-44	44-62		17-23	36-48
			B		4.5-6.0	6-8	10-13	17-22	25-33	34-44		13-17	27-36
			C		3.5-4.5	4.5-6.0	7.5-10	13-17	19-25	26-34		9.5-13	21-37
12	14 x 14	180-210	A		5.5-6.5	7.5-9.0	11-15	18-25	27-36	39-52		14-19	30-40
			B		4.0-5.5	5.5-7.5	8.5-11	14-18	21-27	30-39		11-14	23-30
			C		3-4	4.0-5.5	6.5-8.5	11-14	16-21	23-30		8-11	20-23
12½	15 x 15	210-240	A		4.5-5.5	6-8	9-13	17-22	23-31	34-44	53-70	13-16	25-34
			B		3.5-4.5	4.5-6.0	7-9	13-17	18-23	26-34	40-53	10-13	20-25
			C		2.5-3.5	3.5-4.5	5.5-7.0	9.5-13	14-18	20-26	31-40	7-10	16-20
13½	16 x 16	240-270	A		3.5-5.0	5-7	8.5-11	14-19	21-27	30-39	47-61	11-14	23-30
			B		2.5-3.5	4-5	6.5-8.5	11-14	16-21	23-30	36-47	8-11	18-23
			C		2.0-2.5	3-4	5.0-6.5	8.5-11	12-16	18-23	28-36	6.5-8.0	13-18
14	17 x 17	270-300	A			5-6	8-10	13-17	18-24	27-35	42-54	10-13	20-26
			B			4-5	6-8	9.5-13	14-18	21-27	32-42	7-10	16-20
			C			3-4	4.5-6.0	7.5-9.5	11-14	16-21	25-32	5.5-7.0	12-16
15	18 x 18	300-340	A			4.5-5.5	6.5-9.0	11-15	17-22	23-31	37-49	8-11	19-24
			B			3.5-4.5	5.0-6.5	9-11	13-17	18-23	28-37	7-8	15-19
			C			2.5-3.5	4-5	7-9	10-13	14-18	22-28	5-7	11-15
15½	19 x 19	340-380	A			3.5-5.0	6-8	10-13	15-19	22-27	33-43	7.5-10	17-21
			B			2.5-3.5	4.5-6.0	8-10	12-15	17-22	26-33	6.0-7.5	13-17
			C			2.0-2.5	3.5-4.5	6-8	9-12	13-17	20-26	4.5-6.0	10-13
16	20 x 20	380-420	A				5.5-7.0	9-12	13-17	18-25	30-39	7-9	15-19
			B				4.0-5.5	7-9	10-13	14-18	23-30	5-7	11-15
			C				3-4	5.5-7.0	8-10	11-14	18-23	4-5	9-11
17	21 x 21	420-460	A				5.0-6.5	8.5-11	13-18	17-22	26-35	6.5-8.0	15-18
			B				4-5	6.5-8.5	10-13	13-17	20-26	5.0-6.5	11-15
			C				3-4	5.0-6.5	7.5-10	10-13	16-20	4-5	8-11
18	22 x 22	460-500	A				4.5-6.0	8-10	11-14	16-20	24-32	6.0-7.5	12-16
			B				3.5-4.5	6-8	8.5-11	12-16	19-24	4.5-6.0	9.5-12
			C				2.5-3.5	4.5-6.0	6.5-8.5	9.5-12	15-19	3.5-4.5	7.0-9.5
19	23 x 23	500-550	A				4.0-5.5	6.5-9.0	10-13	14-19	23-29	5-7	11-15
			B				3-4	5.0-6.5	8-10	11-14	18-23	4-5	9-11
			C				2.5-3.0	4-5	6-8	8.5-11	14-18	3-4	6.5-9.0

* See Fig. 53.

FIG. 54. Design Data for RLM Dome Reflectors

LEVEL OF ILLUMINATION.—Footcandle values of illumination are determined from the job requirements and the Recommended Minimum Standards of Illumination given in "Recommended Practice of Industrial Lighting" of the Illuminating Engineering Society.

LAMP WATTAGE.—From a design-data table for the type of luminaire selected, such as the one shown in Fig. 54 for a typical direct lighting fixture, the line corresponding to the luminaire spacing is selected, and the mounting height checked to make sure it is greater than the minimum. If it is, the average footcandles reading for the particular room factor is found in the columns at the right and the heading for that column gives the lamp wattage to be used. The design data for the particular luminaire selected must be used, of course, for this purpose.

LIGHTING FOR THE MORE DIFFICULT SEEING TASKS.—Lighting recommendations for the more difficult seeing tasks are given in "Recommended Practice of Industrial Lighting" under the following groupings.

Group A. Certain seeing tasks involve (1) the discrimination of extremely fine detail under conditions of (2) extremely poor contrast, (3) for long periods of time. Examples are: automobile finishing and inspection; cutting, inspecting, and sewing dark cloth goods or dark gloves; extra-fine shop inspection work; extra-fine bench and machine work and grinding; testing extra-fine instruments; drawing-in operations in cotton, silk, and rayon industries; grading and sorting tobacco products. To meet these requirements, illumination levels above 100 footcandles are recommended.

To provide illumination of this order, a combination of at least 20 footcandles of general lighting plus specialized supplementary lighting is necessary. The design and installation of the combination must provide not only a sufficient amount of light but also the proper direction of light, diffusion, eye protection, and in so far as possible must eliminate direct and reflected glare as well as objectionable shadows.

Group B. This group of visual tasks involves (1) the discrimination of fine detail under conditions of (2) a fair degree of contrast (3) for long periods of time. Examples include: fine assembly; automobile assembly lines; inspection in glass works; fine inspection; fine bench and machine work, fine automatic machines, medium grinding, fine buffing and polishing; fine hand painting and finishing; tin-plate inspection in sheet-metal works; stitching dark materials in shoe manufacture; inspecting tin plate and other bright surfaces in steel and iron manufacture. Illumination levels from 50 to 100 footcandles are required.

To provide illumination of this order a combination of 10 to 20 footcandles of general lighting plus specialized supplementary lighting is necessary. Design and installation of the combination system must meet requirements the same as those stated under Group A.

Group C. The seeing tasks in this group involve (1) the discrimination of moderately fine detail under conditions of (2) better than average contrast, (3) for intermittent periods of time. Examples are: in candy making, milling, hand-decorating, die cutting and sorting; in glass works, fine grinding, polishing, beveling, etching, and decorating; in drafting, prolonged close work; in shoe manufacture marking, sorting and other operations on dark materials, and stitching light materials; in steel mills,

inspecting black plate and inspecting bloom and billet chipping; in cotton manufacture, inspecting grey goods; in silk and rayon manufacturing, warping on creels, on running ends, on reel, on beam, on warp at beaming; in woodworking, fine bench and machine work, fine sanding and finishing.

The level of illumination required is about 30 to 50 footcandles and in some instances may be provided from a general lighting system. Oftentimes, however, it will be found more economical and yet equally satisfactory to provide from 10 to 20 footcandles from the general system and the remainder from specialized supplementary lighting. Design and installation requirements are as stated under Group A.

Group D. The seeing tasks of this group require the discrimination of fine detail by utilizing (1) the reflected image of a luminous area, or (2) the transmitted light from a luminous area. Among such examples are: in glass works, fine grinding, polishing, beveling, etching, decorating and inspection; in sheet-metal works, punches, presses, shears, stamps, welders, spinning, medium benchwork, tin-plate inspection; in steel and iron manufacturing, inspection of tin plate and other bright surfaces.

The essential requirements are (1) that the luminous area shall be large enough to cover the surface which is being inspected, and (2) that the brightness be within the limits necessary to obtain comfortable contrast conditions. These requirements involve the use of sources of large area and relatively low brightness in which the source brightness is the principal factor rather than the footcandles produced at a given point.

Special cases. In steel and iron manufacturing, in the work areas for cold strip, pipe, rail, rod, tube, universal plate, and wire drawing, and in the merchant and sheared plate mills, many of the machines require one or more supplementary lighting units mounted on them, effectively to direct light toward the working points.

In modern plants fluorescent lighting systems are not installed when levels of illumination are to be as low as from 10 to 20 footcandles. The general level for such installations is established at from 30 to 50 footcandles, with supplemental lighting furnished where higher local intensities are needed.

HEAT FROM LIGHT SOURCES.—Heat from light sources is of two kinds—radiant heat and local heat due to convection and conduction. Of the total energy dissipated by a 100-watt gas-filled tungsten lamp, 67% is radiant heat, 25% local heat, and the remaining 8% is light radiation. **Radiant heat** is particularly noticeable and may affect material or worker comfort where a high level of illumination is obtained by a high-wattage supplementary spot- or floodlight. If supplementary lighting is from a nearby fixture, **local heating** also enters. In lighting showcases, refrigerators, or other confined spaces, the effect of both radiant and local heat on the product may be a necessary consideration.

Fluorescent lamps, being about three times as efficient as incandescent lamps, generate less total heat for a comparable wattage. Further, only about one-third to one-half of the total heat is radiant.

EXTERIOR LIGHTING.—Lighting of buildings and grounds at night is used for (1) illumination of dark passageways and driveways, (2) exterior work such as platform loading and rush construction, (3) protection from prowlers and saboteurs, and (4) advertising. From the

standpoint of protection, the work of the watchman is made easier, and detection of an intruder more certain, and, in addition, the intruder is discouraged from trying to enter.

Supply lines to exterior lights should not be unsightly and also should be designed from the standpoint of safety. Switches should be available only to authorized persons, or they may be controlled automatically by time switch or photoelectric relays.

MAINTENANCE OF ARTIFICIAL LIGHTING.—Frequent attention to maintenance of artificial lighting will be adequately compensated for by all of the advantages of good light. The factors are:

1. Collection of dirt on lamp and luminaire. Within the first month, dirt alone may cause an 18% decrease in the level of illumination, but this is readily corrected by regular wiping or washing of the lamp and fixture at short intervals.
2. Conditions of walls and ceilings if they are important reflecting surfaces.
3. Replacement of burned-out lamps. Often a lamp should be replaced before it is burned out, since, due to incandescence, tungsten filaments evaporate and deposit a dark coating on the inside of the bulb, thus reducing efficiency.
4. Elimination of undervoltage operation. Incandescent lamps are much less efficient when lighted by undervoltage. Fluorescent lamps are less affected by small undervoltages, but a 10% drop will cause a decided flicker and a 30% drop an outage.
5. Correct combination of lamp and luminaire. Many luminaires are designed to be used with certain types or sizes of lamps and will be less efficient when otherwise used.

The combined influence of all of these factors, as shown in Fig. 55, can easily cause a 50% reduction in the level of illumination. Dirt on lamp, luminaire, or walls and ceiling is the chief cause and is the least readily noticed. As dirt accumulates gradually, the loss of light will not be noticed by the average workman until long after his task has become more difficult and tiresome, his efficiency lowered, and other disadvantages of poor light have set in.

OBTAINING BETTER ILLUMINATION BY PAINT COLOR CONTRAST.—The dull or gray walls and ceilings of many factories,

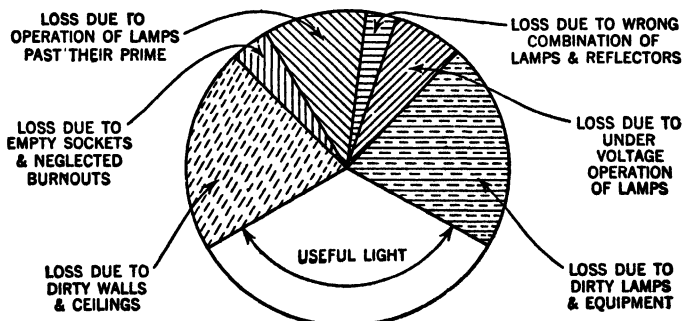



FIG. 55. Possible Reduction in Useful Light Resulting from the Combined Losses Caused by Continued Maintenance Neglect

the dark bands or dadoes along working areas and on stairways, the dark unfinished or deep gray floors, and the grays and blacks on most machines and equipment are not only uninspiring and often unsightly but also cause a sharp decrease in the efficiency of both daylight and artificial illumination. Studies made to measure the extent of losses suffered from a lack of knowledge of the proper paints and colors to use in plant interiors and ón equipment show that merely by correct repainting the intensity of illumination may be increased in many cases more than 100%. The reason for this large increase is that dark colors absorb light while the proper lighter colors reflect it, so that ceiling, walls, floors, and machines throw back on working areas a large percentage of otherwise lost illumination.

Investigations reported by Brainerd and Denning (Improved Vision in Machine Tool Operations by Color Contrast, Illuminating Engineering Society) covering work done on a shear and a punch press painted with light colors around tool areas and with a light or medium gray or a green background on other parts of the machines yielded the results shown in Fig. 56 under the different kinds of lighting indicated and the colors listed. Much, if not all, of the light reflected previously had been absorbed by dark surfaces. As shown in Fig. 56, and in detail in Fig. 57, the over-all work-times of the jobs were likewise reduced when lighter paint was substituted for the former dark grays or blacks.

Readings in the above studies were taken with the Macbeth Illuminometer. Illumination was measured in footcandles of light falling on the machine surface. Brightness—a function of illumination and the reflection factor of the surface—was measured in footcandles of light reflected back from the machine.

OBJECTS OF DISTINCTIVE PAINTING.—Briefly, the object of such painting is to bring about clear, three-dimensional seeing instead of the dull, flat effect produced on the eyes by the drab or dark painting of equipment, ceilings, walls, and floors in the majority of present-day offices and factories (Brainerd and Massey, Salvaging Waste Light for Victory, Illuminating Engineering Society). Three-dimensional seeing can accomplish three definite tasks:

1. Provide positive visibility with finishes having high reflection factors, by means of adequate contrast in hue (controlled mild stimulation).
2. Provide an over-all contrast which is not too harsh to prevent continuous, comfortable seeing.
3. Provide a color sensation which is psychologically continuously pleasant and easy to live with.

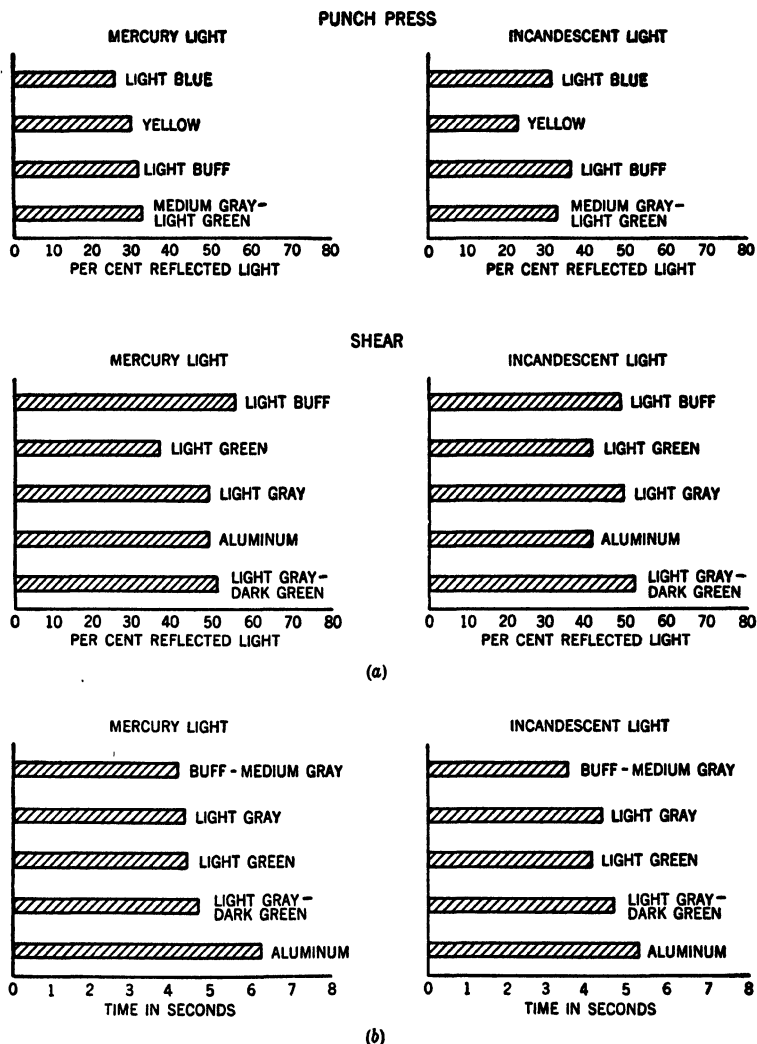
The cumulative result of having all surfaces of high reflection value is to bring out a marked increase in light utilization. This improvement in many cases can be brought about and maintained to more than double the illumination, with no change of equipment and no increase in wattage of lamps (see Fig. 58). Illumination is measured in lumens per square foot falling on a plane, usually horizontal and 30 in. above the floor. The area of the plane in square feet multiplied by the illumination in footcandles gives the number of useful lumens. This figure divided by the rated lumens of the lamp or lamps gives the coefficient of utilization. If the light output of the luminaire instead of that of the

(a) Average values of the per cent of light reflected from machine surfaces
(b) Average of three time studies for different colors applied to the shear

FIG. 56. Per Cent Reflected Light on Shear and Punch Press by Use of Proper Paint Color Contrast, and Corresponding Times for an Operation

Color of Paint	Time in Seconds			Rating—Per Cent*				Final Per Cent Rating
	Job No. 1	Job No. 2	Marking	Job No. 1	Job No. 2	Marking	Average	
A. MERCURY LIGHT:								
Buff and medium gray	4.80	4.00	3.70	78.7	100.0	100.0	92.9	100.0
Light gray	3.78	4.00	5.20	100.0	100.0	71.2	90.4	97.2
Light green	3.82	4.30	5.00	99.0	93.1	74.0	88.7	95.5
Aluminum	5.17	7.67	6.00	73.1	52.2	61.6	62.3	67.1
Light gray and dark green	4.61	5.39	4.10	82.0	74.3	90.2	82.2	88.5
B. INCANDESCENT LIGHT:								
Buff and medium gray	4.60	3.10	3.00	79.8	100.0	100.0	93.3	100.0
Light gray	3.67	5.44	4.00	100.0	57.0	75.0	77.3	82.8
Light green	3.78	4.10	4.50	97.1	75.6	66.6	79.8	85.5
Aluminum	4.25	6.60	5.00	86.4	47.0	60.0	64.5	69.1
Light gray and dark green	4.50	5.00	4.50	81.6	64.0	66.6	70.7	75.8

* The color with the fastest time for each job is assigned a rating of 100% for that job, other times being expressed in per cent of this fastest time. The Average Rating column gives the average of these percentages for each color. In the Final Rating column, the color with the highest average rating is assigned a final rating of 100%, the other colors being rated as percentages of this value.

FIG. 57. Time Studies as Affected by the Painting of Machine Work Areas

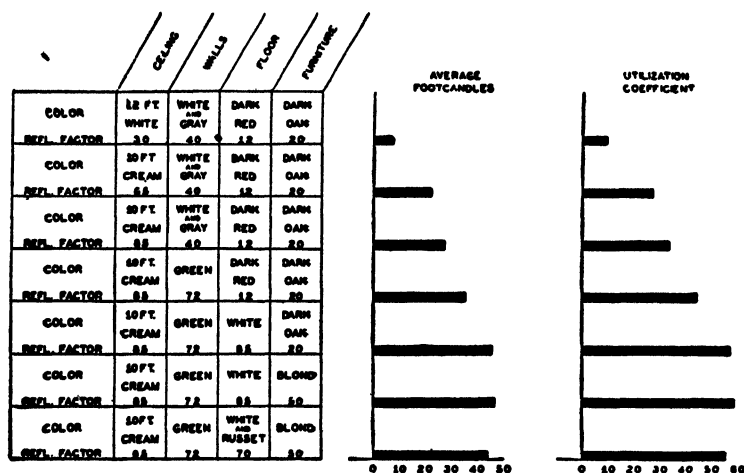



FIG. 58. Effect of Color of Ceilings, Walls, Floors, and Furniture on Light Utilization

rated output of the lamp itself is used as the divisor, the coefficient of utilization is larger. Higbie (Lighting Calculations), on the basis of maximum theoretical utilization factors for various reflection-factors in an ideal room, shows that with 98% reflection the utilization can be 5,000%.

SUITABILITY OF COLORS.—The suitability of a color for purposes of increasing contrasts and intensifying the amount of illumination depends upon: (1) its reflection factor, or relative amount of light thrown back from its surface; (2) its absence of glare—this being accomplished by eliminating gloss through the use of an eggshell finish; and (3) its hue, value, and chroma. The latter three terms (Munsell System) are defined as follows (Brainerd and Massey):

Hue, the quality distinguishing one color from another. This property is designated by the common color names—red, blue, green, etc.

Value, the quality by which a light color is distinguished from a dark one, light colors being high in "value," dark colors low. For any hue there are specified values—light green, dark green, etc.

Chroma, the quality by which a bright or pure color is distinguished from one which is grayed, the former being "strong" and the latter becoming "weaker" in chroma the grayer it becomes.

So-called "spotlight" colors in the range of the spectrum where there is the greatest eye sensitivity are best for good seeing, while weak colors of low chroma are more comfortable on surfaces continuously in the line of vision. Spotlight buff has a reflection value of 68%, is in the region of eye sensitivity, has low chroma, and is psychologically acceptable. Spotlight green has the same reflection value, is a little lower in sensitivity

value, has a somewhat higher chroma and has a wide range of psychological acceptance, particularly in the textile industry. Horizon gray has a moderate reflection value, 34%, is achromatic or neutral in color, and is acceptable for backgrounds. The "horizon" is that part of the wall immediately above the floor (3 to 4 ft.), when finished to aid illumination.

BASIS OF IMPROVEMENTS BY COLOR-CONTRAST PAINTING.—The following factors form the basis of improvements in illumination in plants and offices (Pittsburgh Color Dynamics, Pittsburgh Plate Glass Co.). Eye fatigue is caused by unnecessary travel of the eye over ill-defined areas, tension in holding the eye on work where the surrounding areas are of about the same color, and constant adjusting when changing from light surfaces to dark surfaces. "Focal" colors center the worker's attention on working points. Receding colors on surrounding machine parts cause these to drop back and relax the eye. A "vista" green is suitable for most cases, but in certain cases (food or drug plants, etc.) white produces a more sanitary appearance. **Double contrast** between the work itself and the immediate work area is necessary for more accurate distinction. The work area color therefore must give satisfactory contrast with both materials and surrounding machine parts (frame, bed, etc.). In addition, cool colors offset the psychological effects of unavoidably high temperatures in workplaces, and warm colors similarly offset the effects of cold workplaces.

Attention to machine painting must be accompanied by corresponding care regarding walls, columns, partitions, doors, work or tool cabinets, ceilings, roof trusses, overhead cranes or conveyors, piping, factory floors, aisles, and other objects or areas within the workers' field of vision. **Walls, columns,** etc., should have approximately the same general **tone of color**—not necessarily the same color—as machines and work areas. A vista green is good for walls within the workers' vision as they glance up from their work, and brighter colors, such as yellow, for other walls to gain the benefit of simulated sunlight. If work in a department is done on colored materials, the machines and walls should be painted in the complementary color to prevent the image of the work from appearing momentarily in the workers' vision when they look up. When there are numerous roof trusses, or wires, pipes, etc., overhead they should be made to recede into the background by proper painting. If the **ceiling** has little reflection value, a lighter blue can be used to produce this blending effect. For indirect lighting, of course, colors with a high reflecting value are necessary.

Floors should be painted in a light color with good reflectivity. Where good visibility is necessary below as well as above work, as for example, in many assembly operations done on the floor, light gray is often used for the floor. Tops of benches should be light for bench assembly and related work. Even where it is not necessary to have light floors under and around equipment, it is best to paint the aisles light and to band them along each side to form traffic lanes, in a distinctive, bright color, perhaps focal orange, both to mark them off as traffic limits for the safety of workers at machines, and to keep them clear of materials, finished products, tools, boxes, benches, and other objects. Platforms, ladders, steps, large assembly jigs, and other auxiliaries used in operations, such as in aircraft plants, should be painted a distinctive bright color to mark them off from the surroundings and for safety in use

Moving equipment—industrial trucks, cranes, conveyors, etc.—is a source of accident hazards which can be cut down by proper distinctive painting. Trucks may be painted yellow all around, including any side projection, because this color has high visibility. Boxes, racks, etc., used for moving work from place to place may be painted green to distinguish them from trucks. If the insides of such receptacles are painted in light colors, it is easier to see how much material they contain. Overhead cranes and crane hooks painted yellow (sometimes striped in places with black) have high visibility and thus are noticed as they move over areas in which workers are operating. There is less likelihood of accidents from crane operation when this practice is adopted.

The data in Fig. 59, developed from practices recommended by the Pittsburgh Plate Glass Co., indicate the general application of colors for highest illumination value and most effective color contrast. They should preferably be worked into combination with the aid of expert advice from qualified engineers.

The paints and enamels on the market for equipment painting produce a quick-drying surface with a durable and cleanable finish. They are tough and resistant to softening from oil or grease. They have high adhesion qualities and will withstand expansion and contraction caused by temperature changes.

USE OF THE COLOR SELECTOR.—To aid in selecting the correct paints for three-dimensional seeing at the actual working points on machines, and for ceilings, walls, horizons, and floors, color selectors have been developed and are used by engineers of the companies making painting surveys for improving illumination. The selector diagrammed in Fig. 60 (Brainerd and Massey) has three concentric circles at the right, the outer ring being painted with gray, the inner ring with buff on one side of the card and green on the opposite side, and the middle A being a hole or window which is placed over the material being fabricated. When materials in use are of different colors, several samples must be tested. The color in the inner ring which offers the most desirable hue contrast with the material as seen through the hole determines the paint to be used for working points on machines.

At the left in the diagram is a slide which can be moved to bring several ceiling, wall, horizon, and floor combinations in front of the hole or window B, to get the best background colors. Gray is often the basis but for sewing machines or assembly lines where large horizontal areas may be present and high reflection value is important, other finishes may be more acceptable. Wherever possible, they should be neutral. These carefully selected combinations have been developed from study and experience and can be used continuously without undue eye fatigue. At the same time they give proper contrast with the colors at working points and bring about the maximum utilization of light in the department.

AUXILIARY FEATURES OF PROPER PAINTING.—Painting does not take the place of guards and safety devices on machines, or instruction in safe procedures of operation. Nor does it remove the need for the use of red to indicate fire exits, fire-fighting equipment, switch boxes, emergency stops on machines, and other safety installations or danger points. Rather it is an auxiliary factor aiding in the safety pro-

Name	Use
Focal White	Machine beds, frames, and working points, where sanitary reasons indicate white (as in food manufacturing)
Focal Ivory	Working points on machines
Focal Buff	Working points on machines, or areas immediately adjacent
Focal Green	Machine frames, beds, uprights, etc., horizons, or entire walls forming a background behind equipment
Focal Light Gray	Aisle floors, in certain cases working areas on machines
Vista Green	Horizons, dadoes, or entire walls forming a background behind equipment, where workers see the walls in looking up from work
Focal Blue	Ceilings—to blend in roof trusses, etc.
Focal Deep Yellow	Cranes, hoists, conveyors operating near workers, industrial trucks and tractors, machine handles and wheels, and other moving or operatable elements
Focal Light Yellow	Walls, columns, etc., not immediately within workers' vision. This color simulates sunlight
Focal Beige	Machine areas adjacent to working points
Focal Red	On switch boxes, start and stop button panels, fire-fighting equipment, exits, and other safety devices and danger points
Focal Orange	Working platforms, ladders, etc., and marking off bands along each side of traffic lanes, especially where industrial trucks are used
Focal Dark Gray	Floors where high reflection is not needed, areas under machines or where workers stand, and traffic aisles
Focal Black	Bands on materials handling equipment, stripes at dead ends, turns, etc., in aisles
Standard Identification Colors	On valves or certain fillings to distinguish the nature of the service (steam, compressed air, etc.). The remainder of the piping should be painted to blend in with its background.

Fig. 59. Focal Colors for Room and Equipment Painting

gram through the protection afforded by good illumination. Painting of pipes to distinguish their contents can be harmonized with the plan of painting for the best illumination. It is becoming customary to paint the identification color on only a small section of the pipe at the intake or outlet valve, or on the fitting itself at such points, or on the pipe at certain key points, and to paint the remainder of the pipe in some color which blends it with its surroundings.

HEATING SYSTEMS.—In selection, technical design, and operation of a heating system, the aims are proper balance between investment and operating costs, simple, effective operation, and comfort of workers. Various systems may be classified according to the heating medium or character of equipment used, as (1) hot water, (2) steam,

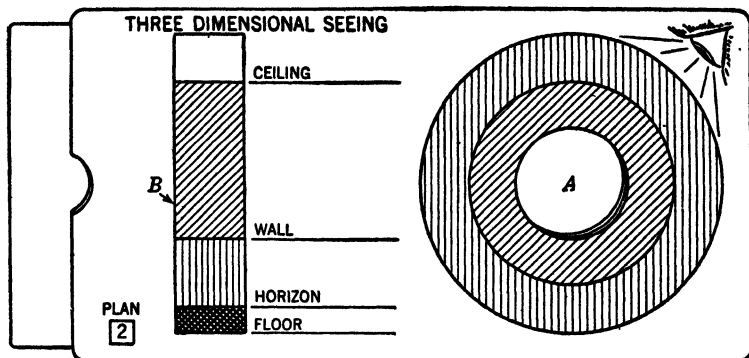



FIG. 60. Color Selector for High Efficiency Painting

(3) vacuum, (4) vapor and vapor-vacuum systems, and (5) unit heaters. Frequently combinations of two or more systems are used in one installation. Unit heaters, either floor type or suspended, have met with general favor for many industrial applications. They have the advantages of rapid heating, directed heat, ease of control, simple piping systems, and may be easily located overhead out of the way.

HEAT GAINS OR LOSSES.—Heat by nature seeks equilibrium and will be transmitted from the higher to the lower temperatures. To cool a room below outside temperature in summer, heat gains must be considered. To warm a room in winter, heat losses are important. Heat gains may be by transmission through walls, floors, and ceilings, by air infiltration through cracks, by solar radiation, from motors, electric lights and other similar equipment, and from people. A person at rest normally gives off about 400 B.t.u.'s per hour or with mild exercise 700 B.t.u.'s per hour. Heat losses are by **heat transmission and air infiltration.** Heat from all sources must be considered in the design and operation of heating and cooling systems. Inadequate systems are never satisfactory; oversize systems are costly.

Large areas have problems of their own. In large plants the heat given from heavy power equipment, lighting installations, and outside radiation on clear days may be such as to exceed the need for other heat, even with a temperature as low as 45° or 50° outside. Industrial processes such as those of heat-treating, foundry work, etc., give off heat which must be taken into account. In windowless buildings the excessive heat from light sources creates a problem during warmer seasons.

HEAT TRANSMISSION.—Heat transmission gains and losses through walls, floors, and ceilings depend upon:

1. Area, A, of the partition in square feet.
2. Temperature difference, D, on the two faces of the partition in degrees Fahrenheit.
3. Heat-conducting properties of the partition expressed as a coefficient of heat transmission, U, in B.t.u.'s per hour per square foot, per degree of temperature difference.

The heat, H, conducted through a partition in B.t.u.'s per hour is expressed by the formula, $H = ADU$, the factors being defined in the above tabulation. The over-all coefficient, U, for a partition will depend upon the composite structure of the partition and will vary from about .10 to .70.

Design temperature differences for air cooling are customarily based on those outdoor temperatures which have not been exceeded on more than 10% of the days during the summer. For heating systems, the average minimum temperature over a period of 10 years is commonly used. Practically all systems so designed are sufficiently flexible to be adequate during relatively short periods of extreme warm or cold weather. To design for maximum and minimum temperatures would result in oversized systems which would cost more and operate less efficiently. A system used most of the year justifies a greater investment with the idea of decreasing operating costs.

AIR INFILTRATION.—Air infiltration or leakage of air is of two kinds—that due to wind and that due to local convection caused by temperature differences. The principal leakage takes place around window sash and doors. Infiltration becomes more serious with increased temperature differences and increased wind velocities. Where the wind strikes a wall at an angle, it is the component perpendicular to the wall that should be considered. Air infiltration cannot be accurately determined but experimental data have been collected and tables developed for estimating these gains or losses.

VENTILATING SYSTEMS.—Ventilation systems are readily classified as either natural or mechanical. In the former, normal movements of air currents are utilized, sometimes made more positive and accelerated by mechanical devices. The latter systems utilize mechanical equipment to pull air into the plant, possibly into air-conditioning apparatus, and then to distribute it where wanted. Exhaust fans and ducts may be used to remove bad air.

COOLING SYSTEMS.—Air is generally cooled by passing it over a cold surface chilled either by ice, cold water, brine, or some refrigerant. Air is sometimes passed over ice directly or water from a tank containing ice is circulated through coils over which the air is blown. Such a system is simple and its first cost is low, but the operating cost is relatively high. Mechanical refrigeration is the most common system of cooling air. Such systems are of two types, compression and absorption. In the compression system, a refrigerant in gaseous state is compressed and passed to a condenser where it is cooled and collected as a liquid in a receiver. It then passes through an expansion valve into an evaporator coil where it returns to a gas, absorbing heat from the air surrounding the coil. In the absorption system, ammonia is absorbed in water and then pumped to a generator where heat drives off the ammonia gas. It is then condensed to a liquid, passed through an expansion valve, and evaporated, absorbing heat as in the compression system.

Air cooling may be done either by central fan distribution of air through ducts to a number of rooms or by portable, self-contained units for one-room cooling. To reduce cost of operation, all or part of the air from conditioned rooms is recirculated through the system.

HUMIDIFYING AND DEHUMIDIFYING SYSTEMS.—Air may be humidified in an air washer by spraying water into it or passing the air through a spray or over wetted surfaces. Sprays may be atomizing, in which air at about 30 lb. per sq. in. is used, centrifugal, in which water is distributed from rotating nozzles, or, in high-duty humidifiers, water under pressure of 150 lb. per sq. in. is directed against a projection and thus broken up. An air washer can be used to remove moisture as well as add it by proper control of the water temperature; air tends to become saturated at the temperature of the water as it leaves the washer. If the air is warmed, it will hold more moisture.

Air may also be **dehumidified by absorption.** Silica gel, a porous structure, has the property of absorbing or removing water from air in contact with it. It can be reactivated by heating. Activated alumina, an oxide of aluminum, is sometimes used in place of silica gel.

PURIFYING SYSTEMS.—Two general systems are used to purify air: (1) an air washer, (2) a filter. The air washer used for humidifying air will remove some forms of foreign particles but it is not effective in removing soot or odors. Filters are better used for the latter purpose. Filters are of two types—viscous and dry. **Viscous filters** break a stream of air up into many small fine streams by passing the air through some material such as steel or glass wool. This material is usually coated with oil to which small foreign particles will stick. **Dry-type filters** pass the air through a screen of cloth, cellulose paper or felt, which removes dust by a straining effect. Any filter will get dirty and clogged in the course of time and must be either replaced or cleaned, depending on the design.

AIR CONDITIONING.—Air conditioning is the science of maintaining the atmosphere of an enclosure at any required temperature, humidity, and purity. In the broad sense, air conditioning includes heating and ventilating, as well as cooling, humidifying or dehumidifying, and cleaning of air. A complete air-conditioning system will do all simultaneously: heat or cool as the case may require, attain and maintain other specified conditions. This is what is inferred when the term "air conditioning" is used, though in a general sense heating or ventilating, or any one phase, is at least partial air conditioning.

INFLUENCE OF AIR CONDITIONING.—From an industrial standpoint, complete air conditioning offers the following:

1. Lower manufacturing costs.
2. Improved quality of product.
3. Protection of goods in storage.
4. Improved health of employees.
5. Improved comfort and efficiency of employees.

In some industries **complete air conditioning** is almost indispensable. Materials which are hygroscopic, or absorb moisture from the air, may be damaged or their properties changed unless humidity is carefully controlled. For this reason, printing and lithographic plants and textile mills were among the pioneers in air-conditioning installations. In high-precision manufacture, the manufacture and checking of gages or parts affected by small changes in temperature, air conditioning has simplified production, lessened waste, and cut down time lost in argument. In

food industries and other industries in which products deteriorate rapidly, control of temperature and humidity may reduce spoilage and permit longer storage. Air conditioning has been at least a contributing factor in the location and relocation of some industries. The cotton textile industry, for example, long located in New England partly due to favorable humidity conditions has been enabled to move closer to its source of raw material in the South as economic factors permit.

From the standpoint of **health, comfort, and efficiency,** the Philadelphia Electric Company found that lost time due to colds and similar disorders decreased 33% and 46% in the first and second years, respectively, after the installation of complete air conditioning. In the Drafting and Surveying Bureau of the Detroit Edison Co., a 51.4% increase in efficiency was largely attributed to air conditioning. Many similar experiences have been reported.

REQUIREMENTS FOR COMFORT.—The comfort of an individual depends upon how fast his body is losing heat and upon the absence of fumes, odors, and foreign particles in the air. The rate at which the body loses heat is a function of the temperature, humidity, air movement, and the exercise of the individual. Temperature influences the amount of **sensible heat lost** and humidity and air movement the amount of heat **lost as latent heat** required to evaporate perspiration. Thus a person feels cool or warm depending upon the combination of these factors and will feel just about as warm at 75°F. and 60% humidity as at 79°F. and 30% humidity.

The data in Fig. 61 serve as a general guide to temperatures which are desirable:

Kind of Building or Room	Temp., Deg. F.	Kind of Building or Room	Temp., Deg. F.
Bathrooms	85	Machine shops	60–65
Boiler shops	50–60	Offices	70
Clothing shops	70	Paint shops	80
Factories (general)	65	Shoe factories	68–72
Foundries	50–60	Textile mills	75–80
Hospitals	72–75	Woodworking shops	60–65

FIG. 61. Desirable Temperatures in Various Locations

Humidity conditions for comfort are not so critical as temperature conditions. Experiments conducted by the American Society of Heating and Ventilating Engineers, and at the Harvard School of Public Health, have shown that for ordinary room temperature, few people can detect the sensation of humidity when the relative humidity is varied from 30% to 60%. From the standpoint of health, humidities between 40% and 60% are best. In general, the higher the room temperature, the lower should be the humidity. The comfort charts developed by the American Society of Heating and Ventilating Engineers should be used in studies of temperature and humidity.

Air movement must be maintained at all times, partly for purification, partly for cooling, but its movement should not be perceptible. As a rule, air movements up to about 40 ft. per min. will not cause complaints from drafts. To keep odors below limits of perception and to

clear the air where smoking is permitted, outdoor air must be introduced to dilute room air. The data in Fig. 62, from Trane Air Conditioning Manual, give the amount of outdoor air required for different conditions.

Location	Cu. Ft. per Min. per Person
Auditoriums Spaces in which there is no smoking	5 to 7.5
Open spaces in banks and general buildings	7.5 to 10
Hospital rooms Open spaces in general offices Restaurants and public dining rooms	10 to 15
Directors' rooms Private offices Spaces in which there is heavy smoking	20 to 30

FIG. 62. Volume of Circulation of Outdoor Air Required for Proper Ventilation

DRINKING WATER.—An ample supply of good drinking water is most important. Drinking fountains should be conveniently placed for all groups of workers. Water supply should be filtered and treated as necessary to provide a cool and agreeable drink, in the interest of both health and comfort. Mechanical refrigeration may be provided to cool water during summer months, or ice may be placed on pipe coils at each drinking fountain. A circulating system of cooled water will cost about $1 per worker per year, for plants employing in the neighborhood of 1,000 persons. Fountains should be of such a design that lips do not come in contact with surfaces, and should be located in positions that will discourage spitting in bowls or nearby.

SANITARY FACILITIES.—The location, equipment, and sanitary care of lockers, washrooms, showers, and toilets is governed by factory laws in the various states, which prescribe minimum allowable conditions. A file of pamphlets covering local factory laws and all regulations issued under them should be regarded as necessary equipment by the production engineer and plant engineer. These regulations represent good practice and are a part of good plant housekeeping. Progressive companies usually exceed the minimums in the regulations, as a matter of providing the most satisfactory working conditions and a factor of good policy in labor relations.

Toilet facilities should be of high quality and attractive appearance as a matter of economy in maintenance and carefulness and cleanliness on the part of the workers. Number of closets to be provided is regulated by law in many states. Where no such provision exists, a ratio of one toilet fixture to every 15 or 20 persons may be used. A minimum number of two is generally desirable for each installation. Closets should be in separate booths, with low swinging doors. Urinal fixtures should be of individual type, and preferably of the bowl instead of the stall model. Automatic flushing arrangements are advisable for all fixtures.

Toilet room walls should be of glazed brick or tile or some similar material to provide a sanitary, easily cleaned surface. If only a wainscot-

ing 6 or 7 ft. high of this kind is built in, wall surfaces above should be finished in a hard, smooth, cement plaster or other surface which can be painted and easily cleaned. **Floors** of terrazzo, tile, or cement are suitable. **Partitions** of pressed steel, painted, are neat, attractive, and durable.

Entrance and vestibule doors to toilet rooms should be arranged so that the interior of the room is not visible from outside.

Ample **washing facilities** must be provided. The washrooms should be separate from the toilet rooms, at least divided off by a partition. **Enameled iron sinks** with separate faucets at frequent intervals are suitable for machine shops and other factories where dirt from shop operations requires large amounts of water for its removal. **Individual bowls** are more suitable for other classes of work. The **fountain type of circular fixture** is attractive and efficient.

Good practice requires one bowl for every worker, or the equivalent in fountain facilities. **Soap** should always be furnished, and is most readily and economically provided in liquid or powder form. An abundance of **hot water** should always be available. Paper **towels** will usually suffice. When cloth towels are to be used, a towel service is necessary to issue clean towels and launder dirty ones. For departments where dust, dirt, or heat makes bathing desirable or necessary, **shower baths** should be conveniently available, and connected with dressing or locker rooms.

If space and the layout permit, it is advisable to have washrooms, shower rooms, dressing rooms, locker rooms, and toilet rooms all adjacent, but separated by partitions, for convenience to workers and simplicity and economy of plumbing. **Floors** and **wall wainscoting** in washrooms and shower rooms should be of tile or glazed surfaces similar to the walls in toilet rooms.

Dressing rooms are needed where the workers must change from street clothes into work clothes and vice versa. They should be equipped with **metal lockers** of expanded metal, or otherwise designed to provide ventilation. Where the nature of the work is such that working clothes become saturated with perspiration or unusually dirty, it is desirable to provide separate racks, or preferably wire mesh lockers, for the working clothes to keep them apart from the street clothes and give them opportunity to dry out and air. Workers' towels can be kept in these wire-mesh lockers. When the nature of the work does not necessitate changing clothes, lockers for men may be placed in open areas adjacent to workplaces, if this arrangement will not obstruct manufacturing arrangements.

All toilet, wash, shower and locker rooms should be well lighted and well ventilated. Floors should be washed once a day, walls frequently. All sanitary equipment should be kept in good repair at all times, and should be thoroughly inspected and cleaned daily, with a liberal use of disinfectants.

FACILITIES FOR WOMEN WORKERS.—Lockers, washrooms, shower rooms, toilets, and other sanitary facilities for women employees are governed specially by factory laws in most states, and by regulations issued under such laws. The requirements are practically the same as those stated above for men's rooms. It is preferable to have these rooms in different locations, but where they are adjacent to men's rooms, the

entrances should be on different corridors, or, if along the same wall, should be at least 20 ft. apart.

Rest rooms for women workers are preferably in different locations from sanitary facilities, sometimes near the dispensary. If they adjoin washrooms and toilets they should be separated by walls. They should be reasonably accessible, cheerful, well-ventilated, and quiet. Since they may be used also as smoking rooms, they must be guarded against fire.

PLANT HOUSEKEEPING.—Besides being well laid out and maintained, a plant should be kept clean and orderly. Cleanliness of sanitary facilities has already been discussed. Corresponding care should be given all departments.

A regular routine should be set up for **sweeping and cleaning** which will insure every part of the building being cleaned. Where there is much dust, floors may first need to be sprinkled or a sweeping compound may be used. **Dust accumulations** on walls and other surfaces, including windows, lighting fixtures, and stairways, should be given attention regularly in the interest of efficiency as well as cleanliness. Daily systematic **removal of dirt and rubbish** from floors and around machines is essential. Metal or fibre **rubbish cans** serve as receptacles for refuse and rubbish. They should be kept clean and odorless, and emptied at frequent intervals to preclude their overflowing. **General cleanliness** of the plant is not only conducive to the good health of the workers, but also is a factor in production efficiency and morale.

Collection and removal of **scrap and waste** from processes should be well organized. Such materials are often salvagable at considerable savings. Cans should be provided at points where scrap originates and the individual kinds—iron chips or filings, steel borings, copper, brass, aluminum, and other—should be kept separate in individual cans. **Paper** should be put in separate metal receptacles both for purposes of baling for sale and for fire protection. The salvage department should schedule regular routes to be followed and make **daily collections** of all such materials to keep departments clear and clean, cut down waste and loss of materials, and assemble the various classes of scrap for sale or disposal.

Special Conditions

THE CONTROLLED-CONDITIONS PLANT.—A controversial subject is that of the controlled-conditions plant, or windowless building, which depends solely on artificial lighting and air conditioning. For precision work carried on 24 hr. a day, this type affords the ultimate in uniform conditions. However, there are opposed economic and psychological factors. For example, the completely controlled-conditions plant costs about 50% more than a comparable daylight plant.

Concerning the controlled-conditions plant, Ferguson writes (Fact. Mgt. & Maint., vol. 99):

Some points in their favor are as follows:

1. Uniform quality of product should be more easily attained if men and machines are working continuously and comfortably under uniform conditions of temperature, humidity, lighting, and ventilation.
2. By using three shifts regularly, much less manufacturing equipment is needed than in single-shift operation.

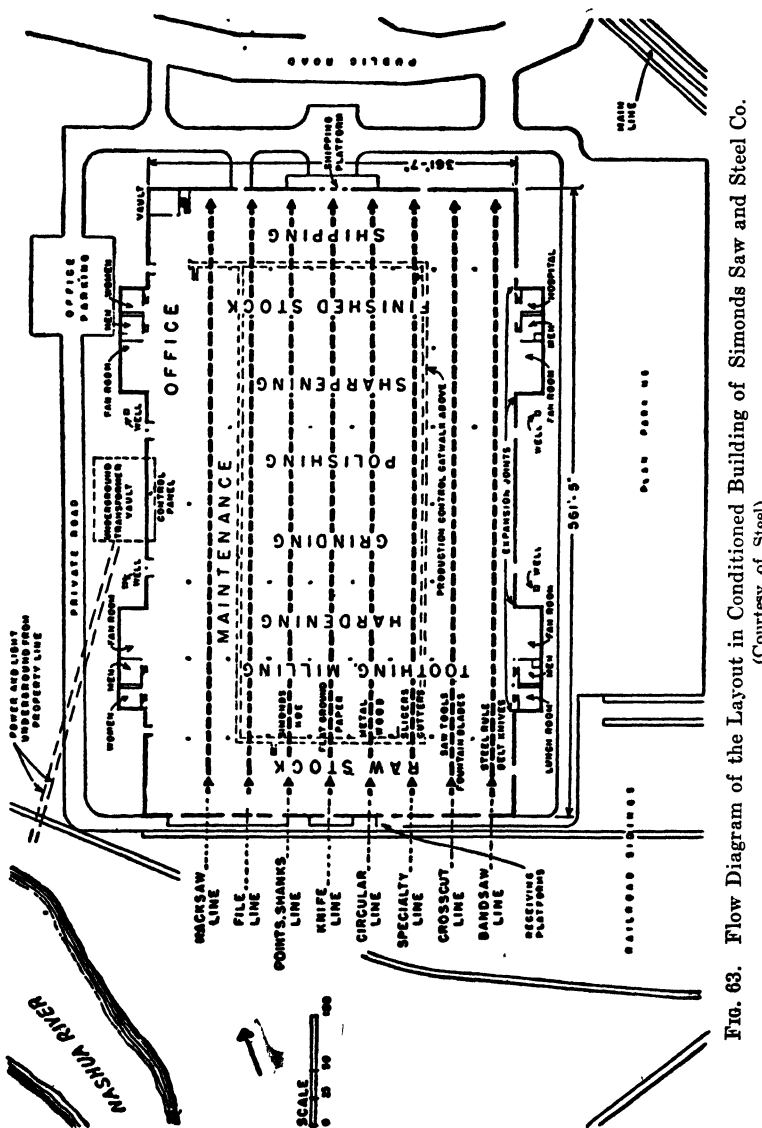



FIG. 63. Flow Diagram of the Layout in Conditioned Building of Simonds Saw and Steel Co. (Courtesy of Steel)

3. Such plants, if not windowless, can be easily blacked out as protection against air raids. In fact they can be designed to operate regularly with little or no light showing.

Some points against this type of plant are:

1. Such plants take longer to design and build.
2. First cost is higher because of the large amount of automatically controlled equipment needed to provide properly controlled conditions. This kind of operation requires plenty of stand-by units to avoid interruptions to plant service and production.
3. Single-story buildings usually cost more to equip than multistory buildings, if they are designed without windows, because of the longer range of distribution of service facilities.
4. Many men still do not like to work where they feel too much inclosed, especially during the day.

An additional problem is that the heat from artificial illumination, while an aid in colder weather, has been found to be so great in some cases that the air-conditioning system has had to be employed for cooling instead of heating the building even in milder winter weather.

In Fig. 63 is shown a flow diagram of the Simonds Saw controlled-conditions plant at Fitchburg, Massachusetts, one of the pioneers in this construction. It is laid out for straight-line production, a line being established for each of its products. Due to practical elimination of noise, heat, fumes, and other objectionable conditions at their source, operations which might normally be segregated from the rest of manufacturing are brought directly to the line. Ability to confine objectionable conditions without partitions has increased the applicability of straight-line production. This possibility exists, of course, for the daylight as well as the windowless plant, but emphasis on control of conditions created by the windowless plant has carried over to benefit the daylight plant.

REMODELING OLD FACTORY BUILDINGS.—When old plants mean higher production costs and competition becomes keen, consideration must be given to betterment of the situation. This may mean a new modern building, or it may mean remodeling the present building. An old building which can be changed and improved to serve adequately the purpose for which it is used may mean a minimum of capital investment, and if so, opportunity for greater profits. Practically any changes in an existing building are possible from a complete rebuilding of the inside, leaving only the original walls, to a rebuilding of the walls alone. The extent to which remodeling is carried must be decided by weighing the cost of changes against anticipated savings. In every case, the state of repair and soundness of the present structure should be investigated.

Of first importance, generally, in remodeling is the layout, or placing the building in step with **improved production procedures.** To permit greater flexibility of layout, certain columns can often be eliminated by using stronger girders to carry the loads to adjoining columns, unnecessary partitions may be done away with, and improved handling equipment installed. Where greater headroom is required, ceilings may be removed; or, vice versa, if ceiling height is greater than necessary, an additional floor may be inserted. If foundations and column structure are satisfactory, additional floors may readily be added. Sometimes a mezzanine floor is more practical than a full floor. Where a court sepa-

rates two buildings, it is sometimes feasible to roof this court over, thus increasing plant floor area.

Other considerations in remodeling are lighting, ventilation, heating, plumbing systems, power, floors, roofs, elevator equipment, insurance costs, and external appearance of building and grounds. In most of these departments, technical developments that bring lower operating costs and rising standards of work conditions, combine with depreciation of installed services to make continued use unduly costly Practically all improved services are readily installed in existing buildings. New factories have more window area than old ones. To remodel the old in this respect, windows may be enlarged by cutting away masonry walls and placing steel angles or I-beams above. Glass area may be increased by using steel sash. Where skylights were not provided on top floors, they can be installed. Improvement in general lighting can be effected by proper painting of interiors and equipment, and installing adequate, modern artificial lighting. Similar improvements may be made in remodeling each of the departments mentioned.

HOW TO DECIDE WHAT CHANGES WILL PAY.—Deciding on changes to cut costs is a problem calling for a combination of business, production, and engineering experience and judgment. What to do, what the expense will be, and the resultant influence on manufacturing costs and profits can be determined. Industrial engineers and architects are prepared to analyze and report on the feasibility of contemplated projects and plans as a basis for executive decisions.

WHEN TO DO THE WORK.—It is probable that most plants should be checked up every few years in any event, because of changes which time brings in connection with designs, materials used, new products, improved machinery available, and newer methods of manufacture and production control. Actual changes may be brought about during low periods of production, either seasonal or cyclical, or immediately preceding starting work on major contracts or new models. **Low building costs** at certain periods warrant anticipating future needs for increased manufacturing space.

SECTION 12

MACHINERY

CONTENTS

SECTION 12

MACHINERY

TECHNICAL AND ECONOMIC CONSIDERATIONS.—In the broadest sense, manufacturing equipment includes all equipment used in the manufacturing industries. In this presentation the term "machinery and equipment" is limited to power-driven machines which are used to change in some way the material being processed as distinguished from small tools, including jigs and fixtures used with manufacturing equipment, and materials handling equipment.

Selection, use, maintenance, and replacement of equipment are major problems of manufacturing plants. In selection or replacement there are two fundamental questions to be considered, one technical and one economic:

1. Will the equipment do the work required in the best way and with the required degree of accuracy, and has it the required capacity?
2. Will it be economically justified by the savings made in cost, time, quality of work, labor, materials, operating methods, and production control?

Because of differences in products manufactured, there are technical differences in the kinds of equipment used in various industries. Even in the same industry there are differences in the nature and capacity of the equipment employed in individual plants. From the technical and operating standpoint, therefore, each plant must study its own equipment problem according to the particular conditions under which it must work. Throughout industries in general, however, the economic question can be answered on the same principles, so that the method of economic analysis used for one kind of equipment can be adapted to other kinds of equipment.

Of all kinds of equipment, machine tools—such as lathes, milling machines, planers, drill presses, shapers, and other common kinds of shop machines—find the widest use. In fact, they have been called the "master tools of industry." Where they are not used in manufacturing they are often employed for maintenance work. Methods used in analyzing the economic advantages of installing new or improved machine tools, therefore, have the widest application and form the readiest basis upon which to make adaptations for analyses of other kinds of equipment. Machine tools—more specifically metal-cutting tools—have been used here, for these reasons, as the most universal example on which to base the discussion of economic analysis for purposes of deciding on the selection or replacement of equipment. As defined by the U. S. Census of Manufactures, a machine tool is "Any machine operating other than by hand power which employs a tool for work on metal."

While considerations of production cost constitute the principal economic basis for the selection and capacity determination of new equipment, or the alteration or repair of existing equipment as compared with scrapping it for new equipment, there are questions of financial and operating policies and procedures to be considered. The objective of an installation—lowest possible cost—is simple, but the problems to be solved in any particular case are often complex and baffling. Methods used by representative companies for making the analyses and deciding on the selection and installation of machines are presented in this section.

Who Selects Equipment?

DEPARTMENTS CONCERNED WITH SELECTION.—In the purchase of equipment, whether for replacements or new installations, several departments are concerned—manufacturing, production control, methods engineering, standardization, inspection, plant engineering, purchasing, the controller, treasurer, and sometimes design engineering. Their responsibilities, from the various standpoints, are listed in Fig. 1. Selection, therefore, should undergo the attention of each of these departments at some stage of the procedure so that all the factors relating to the acquiring and use of new or replacement machines receive proper consideration.

Where no special organization is set up to handle equipment problems, as in small plants, initiation of the study and recommendation usually come from the shops, the production control man, if there is one so designated, or some executive or member of the firm supervising manufacturing operations. The problems are faced as they arise. There are seldom any planned methods for dealing with questions of equipment.

COMMITTEE PLAN OF SELECTING EQUIPMENT.—When a company is of such size that the equipment problem is of relatively large extent, while at the same time executives must divide their time among many activities of an operating nature, usually no one man alone can adequately investigate and settle the question of new machinery. At the same time, it may not be considered necessary to set up a department for the purpose. The advisability of integrating the equipment needs of the entire plant meanwhile is increasing. The solution, therefore, may be to follow some committee plan of handling the question, so that the requirements of all departments may be met with due consideration to the demands of the company as a whole, and all angles concerning any particular installation may be covered.

STANDARDIZATION COMMITTEE.—Larger and more extensively organized companies sometimes have a standardization committee, usually reporting to the factory manager, to which equipment matters may be referred. While such committees are concerned largely with standardization of materials and processes, these questions often involve equipment problems and therefore studies of the latter can be conveniently referred to the committee. Equipment standardization, moreover, is highly desirable from the standpoint of uniformity of equip-

DEPARTMENT	NATURE OF RESPONSIBILITY IN THE INSTALLATION
ENGINEERING—PRODUCT DESIGN	Suitability of new equipment for processing parts of the size, shape, etc., which may be designed, and materials which are to be worked on the equipment. Degree of accuracy obtainable on new machines.
PRODUCTION CONTROL	Suitability, adequacy, and capacity of equipment from standpoint of getting out production. Changes which may be necessary in methods, routings, times, scheduling, etc. Effect on workers—training, wage-rate changes, etc. Relation of new equipment to present equipment from the standpoint of alternate routings, carrying of overloads, etc.
MANUFACTURING	Adequacy and capacity of new equipment for the work. Relation to present equipment. Convenience, reliability, and safety of operation. Changes which may be necessary in methods Required training of, and supervision over, workers.
METHODS ENGINEERING	Changes in processing which the equipment may introduce. Tooling required for new equipment—jigs, fixtures, dies, small tools, etc.
STANDARDIZATION	Standardization of materials, parts, etc., which may be made possible by new equipment. Standardization of routine paper-work procedures, or changes in existing standards, which may be brought about. Standardization of processing methods which may be introduced.
INSPECTION	Nature, amount, and kind of inspection required on work from the new machines. New inspection equipment (electronic gages, etc.) which the installation may make possible. Degree of accuracy obtainable on the equipment.
PLANT ENGINEERING	Requirements as to moving in and installing the new equipment (foundations, floor loads, doorway and elevator sizes, etc.). Power requirements. Maintenance and repairs (location for convenience in repairing, stocks of repair parts necessary, etc.).
PURCHASING	Securing authorization for the purchase, with proper approval signature. Securing proper specifications for the new equipment. Negotiation of an adequate and legal purchase contract, including any necessary guarantees of performance, provisions for acceptance tests, etc.
CONTROLLER	Keeping equipment purchases within the budget, or seeing that proper authorization is secured for buying any special items. Checking the effect of the installation on cost methods and cost data.
TREASURER	Amount of commitment and methods for meeting it. Time when payment must be made to obtain discount.

FIG. 1. Responsibilities of Departments in Installations of Equipment

ment, interchangeability of machines in layouts, reduction of stocks of machine repair parts, developing the most efficient use of equipment, taking and using time studies, training of workers, efficiency of labor, routing of work, preparation of operation and route sheets, machine loading, and dispatching of work.

All these factors have a significant bearing on the kinds of materials used and the methods of processing, both of which obviously must be standardized as part of any plan of mass or straight-line production.

EQUIPMENT COMMITTEE.—A still further development in larger companies is the setting up of an equipment committee which concerns itself mainly with investigations of possible new or replacement machines for the improvement of processing, and to which all suggestions of this nature are referred for study. This committee in most cases reports to the factory manager and its recommendations are usually accepted unless financial reasons prevent.

ADVANTAGES AND DISADVANTAGES OF COMMITTEE PLAN.—In all these committee plans the membership represents most, if not all, departments concerned with the acquiring or use of the equipment. To this extent, the selection meets the requirements and falls within the limitations of all divisions—operating and financial—having some interest in the problem. A frequent disadvantage, however, is that no members of the committee are specialists in equipment. Many of them are well informed about the technical and operating factors of their industry and plant, but from the standpoint of product rather than the efficiency and up-to-dateness of the machinery and devices used for processing. The work of committees, moreover, is regarded as a side issue apart from regular operation of the plant. The committees meet only when necessary, finish their work as quickly as possible to get the matter over, and carry on any outside studies largely in a perfunctory and often short-cut and superficial way.

EQUIPMENT ENGINEERING DEPARTMENT PLAN.—The most advanced and effective way to handle problems of equipment engineering is through either a methods engineering department or a tool engineering department. Either, or both if they exist concurrently, may report to the production control department, or the factory manager, or they may form part of the general engineering organization and report to a chief engineer. The set-up to adopt is that which will produce the best results in the particular company. Eventually, in most cases, the recommendations must meet with the approval of the factory manager.

METHODS ENGINEERING DEPARTMENT.—Under the methods engineering plan, which is often set up to report to the head of production control, all factors concerning the effective selection and application of equipment receive proper attention in a department well organized to handle such duties. The work can be carried on thoroughly as a full-time assignment of competent engineering specialists who must assume full responsibility for the results as far as their studies and recommendations are concerned. These men should be supplied with all texts and reference works on the technical and equipment phases of their industry, all magazines on the manufacturing work of the industry, or dealing with the equipment which it uses, and should be encouraged and aided to keep in touch with professional and technical associations in their field, so that the company may be intelligently abreast of the times in its equipment and operations.

Reports and Records on Equipment.—Details of the methods of operating such a department, studies made, records kept, forms used, recommendation procedures, and other activities vary with the plant and industry, the plans of the management, and the specialties of the problems faced. In any case, adequate reports should be made, used,

indexed, and filed, with a statement as to action taken, so that studies will not be repeated and so that information on the equipment is made readily available to all departments which may need it. Perhaps the equipment records may also be kept in this department, and in that case all reports on machine inspection, condition, maintenance, alteration, moving, etc., should likewise clear through it for extraction of necessary notations.

Coordination of Machinery with Production Control.—An important advantage possessed by the methods engineering department is that it often forms a part of the production control division and therefore may either conduct or be closely associated with all time and motion study work, and likewise rate setting on jobs. Hence it is thoroughly familiar with equipment in action under operating conditions. It is also concerned with the tooling of jobs—including the design, making, and use of all jigs, fixtures, appliances, and small tools required—and the extent to which such devices may be profitably introduced. Its surveys cover methods of processing and layouts of equipment. It is familiar with machine capacities, ranges of work, routing, operations performed, and conditions surrounding the doing of work. Its equipment studies, and recommendations, therefore, will fit in with plant operation to the most effective degree, and it will be definitely interested in following up each machine replacement or installation to see that the equipment is used as intended and gives both the operating and cost-saving results planned.

Need for Keeping Up to Date on Machinery.—Such a department should interview equipment salesman after they are cleared through the purchasing department. Even at times when no equipment changes are contemplated, it is advisable to keep in touch with equipment manufacturers, through their salesmen, to get news of machine developments and the way equipment is being efficiently utilized in other plants. The purchasing department's relations to the buying of equipment are usually only commercial, because it is not often possible to have an expert machinery buyer in the purchasing set-up. At any rate, he would have to be in intimate touch with the whole plant at all times and, if too expert a technician, he may be too poor a buyer. Usually the technical questions regarding equipment buying are left to the engineering department and the shops, and, if the purchase is within the budget and receives the approval of a financial officer to keep the transaction within the general financial program, the order will be put through under standardized purchasing procedure, to cover all business and legal requirements as well as the technical needs.

TOOL AND EQUIPMENT ENGINEERING DEPARTMENT.—Where a tool and equipment engineering department handles equipment problems, it would operate much like a methods engineering department in making studies and determining which machines should be bought. This department sometimes is set- up separately and then usually would report to the works manager or factory manager. Rarely, it might work under the chief designing engineer. Where there is a general engineering department in the company, however, this general department may be broken down into several sections, one of which would be tool and equipment engineering, the others being product

design, special customer design, manufacturing engineering, customer service, or field engineering—including set-up or erection of machinery and adjustments or repair of machinery in customers' plants—testing and product performance, and sometimes plant construction and other branches.

Work of Tool and Equipment Engineering Department.—The tool and equipment engineering section would handle all questions relating to new or replacement equipment, alteration or scrapping of old equipment, determining the remaining use-life of operating equipment for depreciation calculation and replacement purposes, and applying the equipment to serve regular or special manufacturing needs. Many large companies build a considerable part of their special manufacturing equipment, and in this case the equipment engineering section might not merely plan the installations but also design the equipment, supervise its manufacture, and direct its installation through the completion of the trial run, to see that it is operating properly.

SEPARATION OF DESIGN OF SMALL EQUIPMENT.—It is customary to keep the design, manufacture, and application of dies, jigs, fixtures, and small tools separate from those of large equipment and machines. Machine equipment is a fundamental factor involving large problems and heavy expenditures. A mistake results in considerable losses. If the wrong machine is selected, installed, run, and found to be a failure, it can be removed, but in normal times the second-hand price is far below original cost, and the freight, installation and removal charges are not recoverable. Dies, jigs, fixtures, and small tools, however, adapt and fit machine tools to manufacturing operations. They are designed for the needs of particular jobs. Methods studies and time and motion studies are used, directly or indirectly, in planning for such equipment. Problems regarding these accessories are so close to daily operation—in contrast to problems of major equipment with their large investments and long-time aspects—that they are better handled by a methods engineering department whose duties are closely tied in with the current work of running the plant.

HOW SOON MUST NEW EQUIPMENT PAY FOR ITSELF?—When new or replacement equipment is installed, its useful life period is estimated and an amount is written off periodically to reduce its value on the books of the company to zero at the end of this life period. The depreciation charge is regularly included as one of the items of overhead costs charged, on a suitable cost accounting basis, against the products manufactured.

At the same time, the equipment, if well selected and efficiently used, is making manufacturing cost savings considerably in excess of its annual depreciation charges; that is, it is repaying its original cost long before it is worn out or obsolete. While a machine may be assumed to have an estimated useful life of 10 years, it may reduce manufacturing costs sufficiently to repay its purchase and installation price, in, say, 2 years.

There appears to be a general practice in mass production plants to limit to a very few years the time within which a machine must repay its total cost. One typical plan is based upon the assumed relative permanence of methods in effect at the time the installation is made. If there is some doubt of their continued use, the cost must be repaid

within a year. If they appear to be fairly permanent, 2 years, or sometimes 3, is the repayment period. When methods seem to be firmly established with no ascertainable indication of change, a maximum of 5 years is set. Few companies apparently will install any equipment from the use of which they cannot get their money back in 5 years. Over the remaining years of life beyond the repayment period, the equipment will be earning a return on the investment. These facts explain why depreciation may be charged off over 10 years while the company insists on getting its investment in the machine back in, say, 5 years. While assuming a 10-year life of the equipment, the company must protect itself against unexpected obsolescence by recovering the purchase and installation cost within a much shorter period. In addition, profits would be low unless the company could earn a substantial amount over the purchase cost from the use of its equipment.

WHEN IS EQUIPMENT REPLACED?—Undoubtedly the two strongest reasons for making machine replacements are to increase productive capacity and to lower costs. A third reason is to get rid of obsolete equipment or machines that have broken down or are worn out. Another cause is the inadequacy of existing machines to take larger sizes of work, or to turn out jobs within closer tolerances. Fifth, labor and operating problems are reduced by obtaining machines which can be set up in groups allowing one worker to tend two or more machines. A sixth reason is to simplify operations by obtaining equipment, such as semi-automatics and automatics, on which a sequence of operations can be combined instead of doing the work on a series of individual machines. Admittedly, many of these reasons include also an increase in capacity or a reduction in cost, or both. Further reasons are covered later in the check list, Fig. 2, which tabulates the points to be covered in studying equipment to determine its relative condition and usefulness from an operating standpoint.

Equipment for New Manufacturing

NATURE OF THE PROBLEM.—The layout and equipping of a brand-new plant is a major undertaking seldom confronting the production engineer, and will not be discussed here. Equipping to reorganize the manufacture of an existing product, however, or to begin the making of a new product, is not uncommon. The problems are different from those of mere equipment replacement, which usually concerns itself with substituting new and improved machines for those which are inadequate, in poor condition, or out of date.

FACTORS TO CHECK.—Before the factory layout for a new installation can be completely developed the equipment must be selected—kind, capacity, number of units, type or make, size, drive (motor or belt), and other factors. For this purpose, it is necessary to:

1. Obtain drawings or sketches, bills of material and specifications of the product, and list and analyze the materials and parts required.
2. Find out the volume of production to provide for.
3. Obtain or develop operation sheets for the parts, subassemblies, and final assembly or assemblies.

4. List operations according to the kinds of equipment on which they will be performed. Summarize these data. If machine tools are to be arranged by process (kind of work) like operations may be grouped to be done on the same machine or group of machines. Where a product layout is planned for the item or any of its parts, it will be necessary to install machines in the sequence in which the required operations must be performed, which often means some duplication of machines.
5. Obtain estimates on the unit times of operations, allowing for the use of jigs and fixtures, acceptable methods of processing, and the introduction of any semi-automatic or automatic machines. Calculate the daily capacities of the kinds and sizes of machines which it is assumed will be installed, and determine the number of machines of each kind required. Where only limited use of a machine in indicated, perhaps the work can be done on a machine already in the plant, or it may be subcontracted. In either case, routing and scheduling of work will be more complicated.
6. Select the types or makes of machines which appear to be most desirable for the installation. Some machines already available in the plant, and not operating at full capacity, may be used. Where it is necessary to buy new machines, duplicate the types and makes already in the plant, if feasible, to secure interchangeability and simplify maintenance and repair-parts problems. The best machines for the purpose, however, regardless of make, should be chosen. Experienced field engineers of manufacturers can give valuable information answering specific questions about their machines.
7. Develop layouts for the proposed installation. Since the equipment usually has to fit an existing building, the layouts will have to be adjusted to tie in with other machines and departments. Floor loads must be calculated for heavy machines and sometimes such machines may have to be taken out of their desired location and placed on the ground floor where separate foundations can be put in.
8. Investigate the possibility of expanded production, which may change the plans so as to provide certain machines with greater capacity, or may call for a modified layout with excess area available for later occupancy.

Factors on Which Equipment Is Replaced

PLAN OF INVESTIGATION.—Whether machines are replaced according to a definite program or only when some problem in connection with manufacturing arises—such as amount and quality of work being obtained from existing equipment, or the taking on of some new product which necessitates a study of present machining processes and the adequacy and accuracy of the machines in the plant—it is necessary to develop some plan of investigation. In the main, this plan will be to set up, or adopt, a check list of points on which to evaluate the present and proposed replacement machines from the standpoint of technical suitability and cost-saving features.

In all such check lists there will be points to investigate which are related to the particular industry, plant, physical and management conditions and management policies existing at the time and place. But there are numerous factors which are common to practically all cases.

POINTS TO CHECK.—The points requiring attention group into two classes, one covering the physical and technical operating charac-

A. Technical Factors

1. Is the present equipment worn out?
2. Is it obsolete?
3. Is it inadequate from the standpoint of:
   a. Range or size of work
   b. Speed of operation
   c. Accuracy or degree of fineness of work
   d. Strength or rigidity for heavier operations
   e. Rate of output
   f. Insufficient power?
4. Has it been made unsuitable by other changes in equipment in the plant, as, for example, the setting up of a product line of manufacture, or the procuring of other machines working to closer tolerances?
5. Can its operations be more readily done if combined with other operations on an automatic machine?
6. Does it lack the controls, special attachments, and safety features of newer kinds of equipment?
7. Will a new machine do not only the present work but also other kinds of work which the present machine cannot handle?
8. Will a new machine replace hand operations or bench work?
9. Will a new machine have special advantages from the standpoint of:
   a. Ease of set-up
   b. Convenience of operation
   c. Safety, such as guards, stop buttons, etc.
   d. Reliability in performance?

B. Cost Factors

1. Is the cost of keeping present equipment in repair too high?
2. Will the cost of changing or remodeling it for new work be too great?
3. Will spoiled work be reduced by the greater accuracy of new equipment?
4. Will greater output, or a faster rate of production, be obtained?
5. Will one new machine do the work of two or more existing machines of the same kind?
6. Can machine operatives be substituted for skilled craftsmen, thus lowering labor costs by the change?
7. If several machines are to be replaced can one operative tend two or more of the new machines?
8. Will the maintenance cost of the new equipment be less than that of the old?
9. Will new equipment save manufacturing space?
10. Will it be conducive to better work and higher output by the worker?
11. Will it smooth out the production curve?
12. Will it provide the basis for better service to the customer?
13. Will the product for which the machine is to be procured continue to be made for a considerable time, and, if it should later be dropped, will the machine fit into other work?
14. How soon must the machine pay for itself to justify its purchase, especially if products may change?
15. How many years of effective service may be expected from the machine?
16. How will the costs of operating the new equipment be charged to the product?
17. Are funds available for the purchase of the equipment or can the investment be specially financed?

FIG. 2. Points for a Machine Replacement Check

teristics of the machines, and the other taking into consideration the cost and financial factors. The production engineer will concern himself, first, with an investigation as to the technical operating characteristics and limitations of the existing machines, and second, with a survey to see what substitute equipment might be installed and what manufacturing advantages would probably result. If there are no reasons for making a change, he would recommend none.

Usually there are technical advantages discovered, especially since

machine and equipment manufacturers are continually improving their existing products and bringing out improved models or new machinery and devices. Then the question becomes one as to whether it would pay to make the change. A cost study is required to find the answer. While a cost accountant might make the latter study, the points are so interconnected with operating factors that it is better for the production engineer—or the equipment engineer, if a tool and equipment department exists—to make the investigation. Sometimes desired operating advantages are obtained even though no immediate substantial cost saving can be demonstrated.

The items listed in Fig. 2 comprise those which would enter into a check list. For a specific case they can be reworded or readapted and detailed to fit the needs of any industry, plant, or kind of machinery.

Final decisions on making a change rest with some executive who—unless the machine under consideration is of moderate cost and within the normal budget—may have to weigh the question of investment carefully against (1) other needs of the department, (2) requirements of other departments, (3) the financial situation of the company as a whole. It is not impossible for a condition to exist where the changes cannot be financed readily at the time even though there are assured savings to be obtained by installing new machines.

Definite Planning of Machine Replacement

REPLACEMENT PROGRAMS.—Progressive companies have adopted plans of machine replacements according to definite programs instead of waiting until the machinery breaks down or wears out, or until advances in manufacturing methods and equipment make existing installations definitely inadequate, or obsolete. These programs may take several forms:

1. Spending a definite amount of money, or a certain percentage of income, each year to buy machines to replace existing machines that are not in first-class condition, or lack sufficient capacity, or are being superseded by improved models.
2. Replacing every year the oldest or most inadequate machines still in normal use with improved, up-to-date machines of greater accuracy or higher capacity, or with automatic machines doing several operations at the same time.
3. Studying on a planned basis the economy of manufacturing on various machines, or on a series of machines in a product layout, to make replacements where manufacturing costs can be definitely cut.

Although the long depression of the 1930's and the upswing of wartime production had, first, a dampening and then a stimulating effect on machine buying, replacement programs are nevertheless highly advisable during normal periods. They are justified for at least two reasons: (1) the constant advancements in design made by machine tool manufacturers, and (2) the otherwise existing habitual neglect by most industrial plants to make replacements of obviously inadequate and obsolete equipment until necessity forces the step. Actual surveys have shown close to 50% of such outmoded equipment in the average factory in prosperous years.

FACTORS IN THE REPLACEMENT PROGRAM.—The factors justifying a regular replacement program, as followed in the Blanchard Machine Co., were stated thus:

1. It is usually profitable to replace a 10-year-old machine tool.
2. Money set aside to cover depreciation should be spent at once for new machines, because
   a. Depreciation and obsolescence are continuous and must be continuously met by replacements, otherwise the shop will be increasingly handicapped as compared with shops whose equipment is up to date.
   b. Money invested in modern tools earns more than when invested in securities.
   c. Depreciation reserves, allowed to accumulate instead of being promptly used for their intended purpose, offer a temptation to use the money in other ways.
   d. There is less resistance on the part of directors and stockholders to the regular purchase of some equipment each year, than to occasional large expenditures for equipment.

A 10% depreciation rate, and experience showing the cost reduction obtainable by getting rid of machines more than 10 years old, led this company to adopt an annual replacement program amounting in money to 10% of the total replacement cost of all its machine tools in service at the time. Extensions to plant were in addition to the 10% replacement expenditure.

The policy, not the actual percentage figure, was the important element in the program. The shop superintendent kept machine or equipment records on which data showing the age, condition, and efficiency of each machine relative to new models indicated which machines should be studied for possible replacement. From this record the machines were selected whose replacement promised the greatest gain. If the study in any case indicated little or no profit from a change, no replacement was made and another machine would be substituted for consideration. Since the machines were general-purpose tools operating on a variety of work in small lots, it was difficult to apply formulas or to set periods within which any piece of equipment should repay its cost.

The advantages of a planned replacement program, as it was carried on in the Union Special Machine Co., were stated as follows:

1. The time for taking equipment inventories is reduced and, in fact, machine operation need not be interrupted to study the efficiency and determine the condition of the equipment.
2. Attention is constantly directed toward each individual machine. Thus wasteful and inefficient units are quickly detected and exposed with the evidence of their faulty performance prepared in a form suitable for presentation to those in authority.
3. By this method of directing attention to the mechanical equipment, officials of the operating department are automatically forced to keep in touch with all new developments and improvements in methods.
4. The ordering of replacements and repairs is facilitated, and minimum time is wasted by machines idle during operating time.
5. The financial operations of the company are safeguarded through maintaining a constant balance of the appropriation for new equipment and, as a result, by avoiding unexpected expenditures.

The machine record form of this company is shown in Fig. 3

Mach. Mfd. By
Operation
Type Serial No.

MACHINE EQUIPMENT RECORD Dept. No.

Serial Nos. Of Duplicate Machines Involved

*☐ Class A ☐ Class C
☐ Class B ☐ Class D

Date Of Survey	General Condition Of Machine Good Fair Poor	Date Of Purchase	Purchase Cost	% Production Compared To New Type	Quality Of Work—Excel. Good Fair	Type Of New Machine	Condition Of Machine: Must Be Changed	Cost Of Change	Must Be Repaired	Cost Of Repairs	Must Be Over-hauled	Date Required	Cost Of Overhaul

Computation Of Replacement Cost

A—Cost Of Improved Machine
B—Resale Or Trade-In Value
C—Cost Of Change-Over
D—Cost Of Repairs
E—Cost Of Overhauling
F—Net Cost F=A—(B+C+D+E)

Remarks

Economies Effected

Number Improved Type Required
Increase In Production %
Saving In Floor Space—Sq. Ft. X Cost Per Ft
Saving In Maintenance
Saving In Labor Cost
Net Saving
*
Replacement Or Addition?
Is New Machine Recommended?
REMARKS:

Remarks

*NOTE.

Class "A" Denotes Machine Equipment Which For Adequate Reasons Should Be Replaced With A Better Machine.

Class "B" Same As "A" Except Urgency For Replacement Is Not So Great.

Class "C" Covers Equipment Where Specific Recommendation For Replacement Should Be Made After Class "A" & "B" Machines Have Been Replaced.

Class "D" Denotes That Equipment Now In Use Is Found To Be The Best Obtainable For Our Particular Work.

NOTE:
Card To Be Made Out For Each Individual Machine Or For Each Individual Group Of Machines.

FIG. 3. Machine Equipment Record

Machinery Replacement Studies

ECONOMICS OF MANUFACTURING EQUIPMENT REPLACEMENT.—A number of replacement formulas for equipment have been developed, but none of them are entirely satisfactory. It does not seem possible to derive a replacement formula which is both correct in theory and also simple enough for satisfactory use. There are some methods available which are approximate and simple, and which do not require the use of formulas. Certain tabular methods have the advantage of bringing in all the necessary factors and thus making a more reliable estimate. The method which follows is one of this latter kind. (The Selection and Replacement of Manufacturing Equipment, Eng. Ext. Bul. No. 32, Virginia Polytechnic Institute. Also Grant, Principles of Engineering Economy.)

The replacement problem usually involves a **comparison between costs** of performing a certain task by means of each of two or more machines. The method of attack which should be used is entirely independent of accounting methods that may be used in figuring costs of the various items produced by the plant as a whole. That this difference is clearly recognized by many companies is shown by the preceding paragraphs covering the question of how soon equipment should pay for itself. Companies which insist that a new machine show estimated

saving sufficient to pay for itself in 1, 2, or 3 years, handle depreciation on a machine after installation according to their general accounting practice, without regard to the life which is used when making a replacement study.

Replacement problems are generally important enough to justify the attention of an experienced executive. They cannot safely be handled by clerks. Nor is it desirable to make a replacement simply because a replacement study has shown that the replacement would be profitable. It is possible that some other replacement might be even more desirable. A study should be made of equipment as a whole, so as to use money for those replacements that will give the greatest return on funds appropriated for making replacements.

In addition to the cost of the machine itself, the cost of tooling must be considered. Where the machine is used for many purposes, the tooling cost on any job is often small compared to the cost of the machine. In cases where the machine is used entirely for one job, model or product, however, the cost of tooling may bear a high relation to the cost of the machine, and the tools have very high rates of depreciation. In calculating economies of tools, jigs, and fixtures special formulas in that field should be employed. The formulas following are concerned with the replacement of the machines.

EQUIPMENT REPLACEMENT STUDY.—The method outlined below, developed from cost reduction formulas for materials handling, involves finding the total costs, generally on a yearly basis, of producing the desired total output, when using each of the various machines being compared. It is not satisfactory merely to compare the unit costs, with each machine working at its capacity. It often happens that it is profitable to replace a machine even though there is not enough production available to keep the proposed machine operating full time. In such cases the study should be based on the actual expected output and not on the potential capacity of the proposed machine.

Let: I = Investment in present or proposed equipment. For proposed equipment this should be total cost in place ready to operate, and for present equipment it should be present net realizable value, regardless of book value

A = Annual percentage allowance for return on invested capital

B = Annual percentage allowance for taxes, insurance, etc.

D = Annual percentage allowance for depreciation and obsolescence

C = Annual total cost (in dollars) of upkeep or maintenance

E = Annual total cost (in dollars) of power, supplies, etc.

F = Annual total cost (in dollars) of space allotted to machine

M = Annual total cost (in dollars) of material

L = Annual total cost (in dollars) of direct labor

T = Annual total cost (in dollars) of indirect labor

Y = Annual total fixed charges (in dollars) $Y = I\,(A + B + D)$

R = Annual total charges (in dollars) of all kinds against machine for producing expected output. $R = Y + C + E + F + M + L + T$

When tabulating charges, **subscripts may be used to distinguish between different machines.** For example, if subscripts $_1$ and $_2$ represent present and proposed equipment, respectively, I_1 and I_2 will represent investment in present and proposed equipment, respectively. By using additional subscripts any number of proposed machines may be compared with the present machine.

FACTORS IN THE CALCULATION.—If equipment is **replaced on account of obsolescence** before it reaches the end of its originally estimated life, its book value will generally be higher than its realizable value, in which case it is sometimes claimed that the loss which will apparently occur at this time is due to replacement and that this loss should in some way be charged against the new equipment. (Most of the published replacement formulas contain this error.) A consideration of the facts will show that this loss is due to obsolescence of present equipment and appears at this time because of originally overestimating the economic life of the present equipment and by not depreciating it rapidly enough on the books. (This book loss may not be a real loss at all; present equipment may have been so profitable that it would have shown a profit even if all of its true depreciation had been charged against it.) The replacement study should be made on the basis that any difference between book value and realizable value of the present equipment will be charged to profit and loss (or to a replacement account), and the present realizable value (scrap value, second-hand value, or value to the same company for some other purpose) should be used for I_1. A new value should be set for D_1 without regard to the value used when the present equipment was new. It will be noted that if the book value of present equipment is used for I_1, the study will give a result that is unduly favorable to making the replacement, because higher fixed charges on present equipment will indicate higher total costs if present equipment is retained, or, in other words, R_1 will appear greater than it actually is.

If the book value is considerably greater than the realizable value of the present equipment, it will naturally influence the management in deciding whether the replacement should be made. However, as a **replacement study is independent of general accounting methods,** and does not attempt to determine future depreciation policies, it is best practice to use realizable value of the present equipment in the study and to consider separately how replacement would affect the book value of fixed assets. Objection may be made to what appears to be a too drastic writing off of book assets, which might not have been thought of if the replacement had not been considered. **Real assets will not be reduced** and the more correctly the books show the real value of the fixed assets, the less danger there will be of disbursing as dividends what are merely apparent and not real profits. As machine obsolescence cannot apparently be entirely taken care of by regular depreciation methods, it would seem desirable to set up a definite replacement account, to which any difference between book value and realizable value of an obsolete machine could be charged when the machine is replaced.

Less difficulty would be experienced in taking care of this part of the problem if the **real purpose of depreciation accounting** were more clearly understood. Depreciation is charged against products of a machine in order to distribute the capital cost of the machine over its esti-

mated life and to maintain intact the capital of the business. There are many good reasons for distributing this decrease in value uniformly over the life of the equipment, a principal one being that as long as the machine is actually functioning in the plant its value to the company may be considerably greater than its second-hand value. No one knows what the life will be until the machine is replaced, so the depreciation rate which is set according to estimated life is merely an educated guess, and may be entirely too low if it happens that the machine suffers from early obsolescence. When the machine is replaced, depreciation which actually occurred during its life, and which should have been charged against its products, becomes definitely known. If there is a difference between book value and realizable value, this difference represents actual depreciation against this particular machine which should have been charged against its products, and therefore the proper and conservative procedure is to charge this difference immediately to profit and loss or to a replacement account.

If a manufacturing company loses money on an order through underestimating material or labor, such loss is charged to profit and loss and no attempt is made to charge it to future orders. If there has been a loss (or a decrease in profits) due to **underestimating depreciation on a machine,** it should be charged to profit and loss in the same way. It is axiomatic in business that past losses must not be charged to future costs, but this fact is too often lost sight of in machine replacement studies.

No attempt is made here to estimate the **salvage value of a new machine** at the end of its useful life, something which cannot possibly be done accurately in any case. The life of a machine must be estimated in order to set a depreciation rate, but this estimate is itself subject to error on account of possible obsolescence. Inclusion of an estimated salvage value complicates the study considerably, and there does not seem to be any advantage in adding what is simply another uncertain estimate. Any error due to omission of this item will be small and on the side of conservatism. The error will be small because salvage value is always small compared with first cost and therefore its omission merely reduces slightly the apparent profits of replacement by making a small increase in calculated fixed charges.

Interest on invested capital must be considered in making a replacement study, regardless of the accounting methods that may be used in figuring costs and profits. This method assumes that depreciation will be figured by the straight-line method, and therefore it is proper to figure interest, insurance, taxes, etc., on the depreciated value. This is so because, with **straight-line depreciation,** the value on the books of a given fixed asset decreases each year by the amount of the depreciation and therefore interest and similar charges need be considered only on the depreciated value. If it is desired to use the depreciated value in figuring these costs, items A and B may be so chosen as to give average values throughout the estimated life of the machine. If A' is the proper yearly percentage allowance for interest on invested capital and N is the estimated life in years, then $A = 1/2A' \left(\frac{N+1}{N}\right)$. In other words, A is equal to A' for a life of 1 year, is equal to $3/4A'$ for a life of 2 years, and approaches $1/2A'$ for a long life. The same correction may be made for item B.

Item F for **cost of space allotted to each machine** is useful where the machines being compared have different space requirements, but if the proposed equipment will occupy less space than the present equipment, it should receive credit for the saving in space occupied only if the space that is released can be used for some other purpose.

Item M for **cost of material** is included because it has been found that in some cases there is a difference in cost of materials when different machines are used.

Item T for **indirect labor** is included principally because it is desirable to know the total cost of producing the expected output with each equipment. It should be particularly noted, however, that in most cases there will be no decrease in total indirect labor of a department because of a single equipment replacement, and even where indirect labor is regularly figured as a percentage of direct labor, it is incorrect to figure that the saving in indirect labor will be proportional to the saving in direct labor. It should also be noted that item T is generally only a small part of departmental overhead, which also includes items A, B, C, D, E, and F.

It will be found in many cases that there is no change in items F, M, and T, and in such cases the problem may be simplified by omitting these items altogether, provided it is not desired to ascertain the **total cost of producing the expected output** with each machine.

Charles J. Stilwell, President of the Warner & Swasey Co., emphasizes the importance, in problems of equipment purchase and replacement, of taking into consideration the effects of multiple shift operation and labor rate increases because of overtime and double time, etc., on the various factors in the calculations.

EXAMPLES OF REPLACEMENT STUDIES.—In the examples which follow, actual data have been taken from published studies for the first cost of machines and for operating costs. In tabulations of charges, all items have been shown, but values for certain items, such as M and T, have been omitted where no information was available in the published studies.

Example 1. A furniture manufacturer is considering the installation of an automatic machine for boring holes, to replace two machines of the same total capacity. The proposed machine will cost $1,200 ready to operate and will be expected to return its investment in 3 years while earning a return of 15% on the average investment. The present machines cost $650 each and are 5 years old. The life of the present machines was estimated as 10 years, the book value is $325 each, but the realizable value is only $175 each. Fixed charges on the present machines will be based on the realizable value, assuming the remaining life as 3 years, and charging a 15% return on average investment during that period. The remaining life of the present equipment is set at 3 years, rather than the 5 years that are left from the original estimate, because it does not seem reasonable to assume a longer life for a present machine than the period during which the proposed machine is expected to pay for itself. Insurance and taxes will be figured at 2% on average investment.

$$A = 1/2 \times .15 \times \frac{3+1}{3} = .10$$

$$B = 1/2 \times .02 \times \frac{3+1}{3} = .013$$

Solution of Example 1:

Present Equipment (2 machines)	Symbol	Proposed Equipment (1 machine)
$350	I	$1,200
.10	A	.10
.013	B	.013
.333	D	.333
.446	$A + B + D$	.446
350 × .446 = $ 156	Y	1,200 × .446 = $ 534
50	C	35
149	E	110
8	F	4
....	M	....
2,480	L	1,240
....	T	....
$2,843	R	$1,923

The figures in Example 1 indicate that **the proposed machine will show savings** that will not only pay back the increased investment in 3 years, while earning a return on the average investment during this period, but also will show an additional saving in total charges of $920 per year ($2,843 − $1,923 = $920). If the proposed equipment proves to have a life greater than 3 years, the saving in total charges will be greater than $920 per year. If the replacement is made, the difference of $300 between the book value and the realizable value for the two present machines should be charged to profit and loss, to surplus, or to a replacement account.

Example 2. A large metal-working company, furnishing parts to the automotive industry, has been performing a certain type of operation on single-spindle automatic lathes, with one operator for each battery of 4 lathes. Additional capacity is needed which would require 32 additional automatic lathes of the present type. It has been suggested that multi-spindle automatics be purchased instead, 6 of these machines being equivalent in capacity to the 32 lathes of the present type. For purposes of comparison a 4-year life with a 15% return on the average investment will be used. Taxes and insurance are 2%.

$$A = 1/2 \times .15 \times \frac{4 + 1}{4} = .094$$

$$B = 1/2 \times .02 \times \frac{4 + 1}{4} = .013$$

The figures in Example 2 indicate that the annual charges will be $8,090 per year less with the multi-spindle automatics ($71,050 − $62,960 = $8,090). (See following page for solution of example.)

This study is a **selection problem** rather than a **replacement problem.** Let us now suppose that the problem is to determine whether the 32 present single-spindle automatic lathes should be **replaced** by 6 new multi-spindle automatics. Also assume that the book value of the present machines is $48,000, and the realizable value is $32,000. It would seem reasonable to calculate fixed charges on the present machines on an investment of $32,000 at the same rates as in the study just made.

If that is done it will be noted that total charges with these old machines are $48,180 per year ($11,430 + $8,000 + $6,550 + $2,400 + $19,800 = $48,180), showing that it certainly will not pay to make the replacement. On the other hand, if the company were willing to make the replacement on the basis of an 8-year life and 12% return on average investment, the replacement study would show total charges for the multi-spindle automatics to be $44,600 per year.

Solution of Example 2:

Single-Spindle Automatic Lathes (32 machines)	Symbol	Multi-Spindle Automatics (6 machines)
$96,000	I	$120,000
.094	A	.094
.013	B	.013
.25	D	.25
.357	$A + B + D$	.357
96,000 × .357 = $34,300	Y	120,000 × .357 = $42,800
8,000	C	2,400
6,550	E	2,310
2,400	F	600
.....	M	.....
19,800	L	14,850
.....	T	.....
$71,050	R	$62,960

It will be apparent from these examples that the method advocated is extremely flexible, enabling one to use any life period and any return on invested capital that may seem desirable in a given case. At the same time it is possible to determine total annual charges against each machine on the basis of assumptions of capital charges and estimated operating costs. The fact that this method determines the difference between total charges, by first calculating the total charges with each machine, would seem to make the method superior to other methods which merely determine the difference between total charges without giving any information as to what the total charges are with any machine. For instance, there is the same $500 difference between total charges of $5,000 and $4,500 as between total charges of $100,000 and $99,500. Anyone will appreciate that this saving is a material item in the first case, and that it is not worth considering in the second case, because it is less than the probable error in the calculations from which the charges were determined.

DISCUSSION OF THE METHOD.—After total charges against each equipment have been calculated, it is a simple matter to determine which equipment shows the lowest total annual charges, no matter how many machines are being compared. As each machine has already been charged with the rate of return on invested capital and the depreciation rate for which it has been decided that the investment would be desirable, replacement would seem to be in order if the proposed machine, or any one of them, shows a further net saving. Replacement studies are

extremely valuable in bringing to light all tangible factors, but intangible or judgment factors must also be considered. No replacement method will ever be developed that will not require managerial judgment in making the final decision.

No attempt has been made to determine how much money one can afford to invest in a proposed machine, how soon the proposed machine will pay for itself, or what the rate of return will be on the additional investment. None of these factors can be determined correctly without the use of rather complicated mathematical procedures, and fortunately it is not necessary to determine these factors in order to make satisfactory economy studies.

There is no need to determine how much money one can afford to invest in a proposed machine. Either the cost of the machine is already known or an estimate can readily be made of the cost. The problem is merely to determine whether the machine will show an attractive saving after all charges have been assessed against it.

There is no need to determine how soon a machine will pay for itself. A decision should be made as to the period during which the machine will be expected to pay for itself, and the machine should then be charged with a depreciation rate that will force it to pay for itself (plus a satisfactory return on investment) during that period.

There is no need to determine percentage return on additional investment if, as in the method herein outlined, each machine is charged with a return on capital which would make the investment attractive. The essence of the present method is to charge every investment with the percentage return required to make that investment attractive and then to determine whether the saving in total charges with the proposed machine is worth while. This saving may just as well be in dollars per year as in a percentage return on additional investment. To change it into a percentage return is not a simple task, because we have already charged each investment with a return (perhaps at different rates) and the investment is being reduced throughout the life of the equipment through depreciation charges.

The method advocated automatically takes care of cases where the **proposed machine has a greater potential capacity than will be required** at present. In such cases, if the proposed machine cannot show a reasonable saving on the basis of present production, replacement should be postponed until production increases sufficiently, or until some other machine is developed that will show a reasonable saving on the basis of present production.

It is simpler to make replacement studies in cases where the **equipment is a part of a production line** and works continuously on the same product. Replacement studies, however, can be made satisfactorily in cases where equipment is used on many different products, if an estimate can be made of the costs of each product, using both present and proposed equipment. The time required to make such studies will be greater but the general principles will be the same.

In this discussion the replacement problem has been considered from the standpoint of cost alone. There may be many other reasons for making replacements.

Machine Capacity

LIMIT OF CAPACITY.—Manufacturers are convinced that it is profitable to work equipment to the limit of its capacity. The object is both to reduce costs and also to get as much production out of the machine as possible before it becomes obsolete. In order that machines may be worked to the limit of their capacity and still not be overloaded to the extent that they will fail or do poor work, it is necessary that they be carefully analyzed to determine just what the capacity really is. Such an analysis will sometimes show that possible output may be considerably increased by strengthening one or two weak parts.

High-speed cutting tool materials, such as cemented tantalum or tungsten carbide, have made it possible greatly to increase cutting speeds, which requires that more power be applied at the cutting tool and that the machine be stronger and stiffer. **High-production machine tools** have been designed especially for use with these tool materials and are in general stronger and more rigid than the older machines, and with greater power available at the cutting tool. On the other hand, a careful analysis may make it possible to get some of the advantages of the latest cutting materials when using machines that were not originally intended for such high speeds.

The ultimate capacity of cemented-carbide tools has not yet been determined. Even those plants now using them are in most cases probably not obtaining the maximum possible efficiency and savings. In some cases the machine tools now being used may not be rigid enough to withstand the heavy strains that would result from maximum utilization of these new tool materials. On the other hand, most machine tools built during the last decade are probably strong enough and rigid enough to use cemented-carbide tools to advantage. Nonuse of these modern tools is probably due in many cases to inertia, and it behooves industrial management to investigate fully the possibility of using cemented-carbide tools on various kinds of jobs.

Sufficient information on the subject is already available, particularly in regard to ferrous metals, to enable a far wider manufacturing application than is made of cemented-carbide tools—whose use throughout industry in the United States would increase metal-working machine production by perhaps as much as 25% in total, as estimated by one well-known authority on this subject. There has been, however, a lack of extensive data on proper methods for machining nonferrous metals and alloys by such tools. But studies have been undertaken recently to work up considerably more engineering data on the correct speeds, feeds, depths of cuts, tool angles, and other factors, a knowledge of which will vastly widen the application of cemented-carbide tools to the machining of both ferrous and nonferrous metals. A manufacturing engineering committee set up under the American Society of Mechanical Engineers has been in charge of one of the above research projects. Another extensive investigation is that made under the direction of Professor Orlan W. Boston, Chairman of the Metal Processing Department, University of Michigan, who has reported on some of his findings (Mech. Eng., vol. 65). The results of these authoritative studies, applied in industry, will considerably increase the efficiency and utility of machine tool equipment throughout metal-working plants.

Manufacturing equipment may be driven either by belts from line shafting or by individual electric motors. Most metal-working and wood-working machines are driven by individual electric motors; in fact, many of them have several motors. Even with individual motor drive there are likely to be belts for transmitting power to some parts of the machine, sometimes through cone pulleys for obtaining different speeds.

Equipment manufacturers usually furnish their machines with motors of sufficient size to operate the equipment continuously at full capacity, although the actual cycle of operations may require maximum power only a small part of the time. The output of an electric motor is limited only by its heating, provided it can develop sufficient torque to handle the maximum load without too great a reduction in speed. Heating of the motor varies as the square root of the mean ampere squares. By analyzing the actual operating cycle, it may be possible to use a smaller motor than would regularly be furnished. This change results in a lower first cost, a more efficient motor, and a better power factor in case of alternating current induction motors.

Analysis of Machine Capacities

OCCASIONS WHEN ANALYSIS IS REQUIRED.—When new equipment is installed, the production man has no problem of calculating limits of strength of machines or power required. The responsibility for design and analysis lies entirely with the machine builder, and the performance of a machine as to strength, power, etc., is the builder's responsibility. When the problem, however, is whether old or obsolescent machines can be used for heavier duty than that for which they were designed, it may become necessary to make calculations as to the limits of capacity of the machine fixed by its strength, rigidity, and design. While the subject of machine tool design is not within the scope of this Handbook, the following methods will be useful when it is necessary to estimate the capacity of existing machines, their power requirements, and the consequent limits of performance that can be expected from them. The examples given are for metal-cutting machines.

There are three principal kinds of metal-cutting tools: the lathe-planer tool, used on lathes, boring mills, planers, shapers, etc., the milling cutter, and the drill. To determine machine capacities (Production Planning, Hallock) it is necessary to consider the amount of power required in removing metal with each kind.

LATHE-PLANER CUTTING TOOLS.—When a tool removes metal, there is a pressure between the tool and the work. This so-called **chip pressure** depends on many things, such as material being cut, shape and sharpness of tool, and shape and size of chip that is being removed. For the lathe-planer tool a simple and sufficiently accurate formula is:

$$P = CA \tag{1}$$

in which P = Chip pressure in pounds
A = Sectional area of chip in square inches; it is the product of depth of cut and feed per spindle revolution
C = A constant depending on material being cut

Values of C may be found in engineering handbooks. Hallock gives the following as sufficiently accurate for practical purposes:

340,000 lb. per sq. in. for high carbon steel
260,000 lb. per sq. in. for mild steel
130,000 lb. per sq. in. for cast iron
185,000 lb. per sq. in. for cast steel
115,000 lb. per sq. in. for bronze

If chip pressure and cutting speed are known, **power required at cutting edge** is:

$$\text{hp.} = \frac{PS}{33{,}000} \qquad (2)$$

in which P = Chip pressure in pounds
S = Cutting speed in feet per minute
hp. = Horsepower required at cutting edge

It is often more convenient to use value of chip pressure from formula (1), from which:

$$\text{hp.} = \frac{CAS}{33{,}000} \qquad (3)$$

Cutting speed is the rate at which the cutting edge moves past the work or the work moves past the cutting edge. Tables of cutting speeds

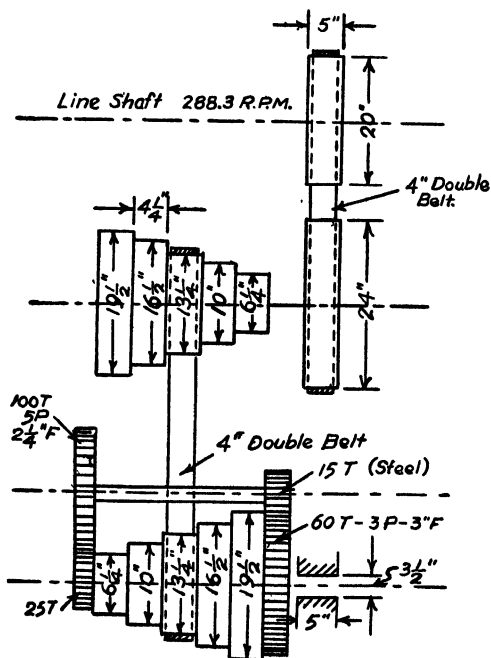



FIG. 4. Analysis Sketch of Lathe

suitable for various materials and cutting tools may be found in engineering handbooks. (Manual on Cutting of Metals, A.S.M.E., etc.) Power determined from formulas (2) or (3) is power required at cutting tool. This must be divided by the mechanical efficiency of the machine to obtain the power requirements of the machine.

LATHES.—To indicate how the capacity of a machine may be determined, an analysis will be made of the cone-driven engine lathe shown in diagrammatic form in Fig. 4 (many of these lathes are still in use). Ten spindle speeds are available, five from the cone pulley driving the spindle direct and five more through back gearing.

Engineering handbooks give various formulas for **power** that may safely be **transmitted by leather belting.** The following simplified formulas are developed from information given by Marks (Mechanical Engineers' Handbook), using average operating conditions for machine tools:

$$\text{hp.} = \frac{WDN}{3{,}000} \text{ for single belting} \tag{4}$$

$$\text{hp.} = \frac{WDN}{1{,}800} \text{ for double belting} \tag{5}$$

in which W = Belt width in inches
D = Diameter in inches of either pulley
N = r.p.m. of same pulley

Using formula (5), power that may be transmitted through the **main drive belt** from the line shaft is:

$$\text{hp.} = \frac{4 \times 20 \times 288.3}{1{,}800} = 12.8 \text{ hp.}$$

In the same way the power that may be transmitted by the **belt between the cone pulleys** is found to be as follows: spindle speed 1, 3.5 hp.; 2, 5.4 hp.; 3, 7.1 hp.; 4, 8.7 hp.; 5, 10.1 hp.

For the five lowest spindle speeds, the power that may be transmitted depends also on the strength of the back gearing. **Power that may be transmitted through the gearing** may be determined by the Lewis formula:

$$W = \frac{sFy\pi}{D} \tag{6}$$

in which W = Safe working load on tooth in pounds
F = Face of gear in inches
s = Safe unit stress of material, at pitch circle speed, in pounds per square inch
y = Strength factor, depending on form of tooth and number of teeth
D = Diametral pitch of gear

Values of s and y for the type of gear tooth generally used on machine tools are given in Fig. 5.

It is evident from the values of y for different numbers of teeth that when gear and pinion are of the same material, only the strength of the pinion need be calculated. When the pinion is of stronger material than the gear, the strength of each should be calculated, or values of s and y for each should be compared to determine which is the weaker. The back

gearing on this lathe is of steel throughout, so only the strength of the two pinions need be determined.

For spindle speed 1-b, the pitch circle speed of the 25-tooth, 5-pitch, steel pinion is 105 ft. per min., so s is 20,000, y is .097, and

$$W = \frac{20{,}000 \times 2.25 \times .097 \times \pi}{5} = 2{,}740 \text{ lb.}$$

The power that can be transmitted by a gear is given by the formula:

$$\text{hp.} = \frac{WS}{33{,}000} \tag{7}$$

in which W = Safe working load on tooth in pounds.
S = Pitch circle speed in feet per minute.

From formula (7), this 25-tooth pinion, at spindle speed 1-b, can transmit power as follows:

$$\text{hp.} = \frac{2{,}740 \times 105}{33{,}000} = 8.7 \text{ hp.}$$

In the same way power that can be transmitted through both the back gear pinions, at each of the five lower spindle speeds, may be determined. For this particular lathe, the back gearing will transmit more power than the cone pulley belt, at each spindle speed, so the power of the belt governs. If the mechanical efficiency of the lathe is 75%, the power available at the cutting tool will be as shown in Fig. 6.

VALUES OF y

No. of teeth..	12	13	14	15	16	17	18	19
Value of y...	.067	.070	.072	.075	.077	.080	.083	.087
No. of teeth..	20	21	23	25	27	30	34	38
Value of y...	.090	.092	.094	.097	.100	.102	.104	.107
No. of teeth..	43	50	60	75	100	150	300	rack
Value of y...	.110	.112	.114	.116	.118	.120	.122	.124

VALUES OF s

Velocity in feet per minute.	100 or less	200	300	600	900	1,200	1,800	2,400
Cast iron	8,000	6,000	4,800	4,000	3,000	2,400	2,000	1,700
Steel	20,000	15,000	12,000	10,000	7,500	6,000	5,000	4,300

FIG. 5. Factors in the Lewis Gear Formula

From formula (3), maximum values of AS may be determined for any material by substituting the proper values for hp. and C. Fig. 6 shows values for AS for mild steel, cast iron, and bronze, using the values for C suggested by Hallock.

Maximum chip area may be determined by dividing AS by the cutting speed. This will be the maximum chip area from the standpoint of power available, but as the maximum chip area depends also on the strength of the machine, it should be checked from that standpoint also. Assuming that the weakest point in the feed mechanism is the 15-tooth, 6-pitch, 1¾-in. face, steel rack pinion (not shown in sketch of lathe),

ENGINE LATHE No. M-91

Swing over bed: 30 in. diameter
Maximum length: 8 ft.

Max. chip area for mild steel: .0053 sq. in.
Max. chip area for cast iron: .0105 sq. in.
Max. chip area for bronze: .0119 sq. in.

Spindle Speeds—Symbol	1-b	2-b	3-b	4-b	5-b	1-a	2-a	3-a	4-a	5-a
Spindle Speeds—r.p.m.	5.0	9.2	15.1	24.6	45.5	79.7	147.7	240.8	392.7	727.2
Horsepower Available at Cutting Tool	2.6	4.1	5.3	6.5	7.6	2.6	4.1	5.3	6.5	7.6
Max. *AS* for Mild Steel Sq. in. × Ft. per min.	.33	.52	.67	.83	.96	.33	.52	.67	.83	.96
Max. *AS* for Cast Iron Sq. in. × Ft. per min.	.66	1.04	1.35	1.65	1.93	.66	1.04	1.35	1.65	1.93
Max. *AS* for Bronze Sq. in. × Ft. per min.	.75	1.18	1.52	1.87	2.18	.75	1.18	1.52	1.87	2.18

Longitudinal and cross feeds available, inches per spindle revolution:
.0143 – .020 – .0286 – .040 – .058 – .080 – .114 – .160

FIG. 6. Analysis of the Capacity of a 30-in. Lathe

the force that can be transmitted through this slow speed pinion may be calculated by the Lewis formula to be 1,370 lb. The front spindle bearing of this lathe is 3½ in. diameter by 5 in. long. At an allowable bearing pressure of 200 lb. per sq. in. on the projected area, allowable pressure on this bearing is $200 \times 3\frac{1}{2} \times 5 = 3{,}500$ lb. For chucked work the pressure on this bearing may somewhat exceed the tool pressure, but as the allowable pressure on the feed mechanism is only 1,370 lb., the feed mechanism is evidently the weakest part and the maximum chip pressure of this lathe, from the standpoint of strength and regardless of how much power is available, is 1,370 lb. With this maximum chip pressure, the maximum chip area may be determined for any material from formula (1). Values of the maximum chip area for this lathe for mild steel, cast iron, and bronze are shown in Fig. 6.

Fig. 6 may be used to find the **proper speed and feed** for any work that can be performed on this lathe, and also to find the time required for the actual cutting operation. Similar tables may be prepared for other machines that use the lathe-planer type of cutting tool.

Preparation of these tables for the **planer and shaper** is made more simple because of the fact that with these machine tools there is only one cutting speed for each machine speed; namely, the table speed of the planer and the ram speed of the shaper. Therefore with the planer and the shaper the table may be made to show the maximum *A* for each speed and each material, instead of the maximum *AS*. With machines of this sort, where there is a quick return motion, the time required per unit length of cut varies in most cases with both the speed of the table or ram and the length of cut. The analysis table should show, therefore, either an average value of the time required per unit length of cut for the complete cycle of working stroke and quick return stroke, or values for both long and short lengths of cut, so that a rough interpolation may be made to get the time required per unit length of cut for the complete cycle at any given length of cut.

If it happens that the power available at the cutting tool depends on the strength of the gearing, such power may sometimes be increased by

using steel gears in place of cast iron gears or by using a smaller diametral pitch (stronger teeth) for the gears. Such a change in pitch, with the same shaft centers, is possible only if the product of the proposed pitch and the distance between shaft centers is a whole number. Clearance should also be checked on account of increased outside diameter of a gear with a smaller diametral pitch.

Use of Fig. 6.—To show how Fig. 6 is used, a determination will be made of proper speed and feed and time required to take one 1/4-in. cut from a mild steel bar 8¼ in. in diameter and 24 in. long. The finished shaft will have a diameter of 7¾ in., and the average diameter may be taken as 8 in. in finding the proper spindle speed.

Spindle speed, in terms of cutting speed, is given by the formula:

$$N = \frac{12S}{\pi d} \tag{8}$$

in which N = Spindle speed in r.p.m.
S = Cutting speed in feet per minute
d = Diameter of work in inches

From formula (8), if allowable cutting speed is 120 ft. per min., maximum spindle speed will be 57.3 r.p.m. Using the next lower available spindle speed of 45.5 r.p.m. from Fig. 6, the actual cutting speed becomes 95 ft. per min. From Fig. 6, available AS is .96, from which the maximum chip area will be .0101 sq. in. But Fig. 6 also shows that the maximum chip area for mild steel is .0053 sq. in., so this value must be used. This chip area divided by the depth of cut shows a maximum feed of .0212 in. per revolution, and next lower available feed of .020 in. per revolution must be used.

Actual cutting time for the operation may be determined from the formula:

$$T = \frac{L}{NF} \tag{9}$$

in which T = Time in minutes
L = Length of cut in inches
N = Spindle speed in r.p.m.
F = Feed in inches per spindle revolution

In this example time required is found to be 26.4 min. It is evident that total actual cutting time for two cuts of 1/8 in. each would also be 26.4 min., as with the same available chip area the feed could be doubled.

For more extensive information on cutting speeds, feeds, and power requirements for single-point tools, see the research report, Manual on Cutting of Metals, A.S.M.E.

ALIGNMENT CHARTS FOR MACHINE OPERATION ANALYSIS.—Information shown in Fig. 6 may be plotted on a series of alignment charts, by means of which much time may be saved in solving a problem like the one just illustrated. Alignment charts are quite simple in theory and use, although actual making of a set is likely to require considerable time. They are great time savers, however, where many problems are to be solved.

The particular sort of alignment chart used in machine analysis solves the equation $a = kbc$, in which k is a constant and a, b and c are variables. The chart consists of three parallel lines (generally vertical) with

logarithmic scales, so arranged that a straight edge laid across the three lines will intersect them at values which satisfy the equation. If there are more than three variables, one of the three lines must represent a combination of two or more variables. For instance, if $a = kbcd$, a chart may be constructed with one line representing the product of c and d and then another chart constructed on the same sheet with additional lines for c and d.

There are a number of methods for constructing these charts. The following example will show a method which is simple in theory and practice.

Let $a = 1/4bc$, and assume that minimum and maximum values are to be 2 and 32 for b, and 1 and 128 for c. Draw parallel lines for b and c, as far apart as convenient, and place on them logarithmic scales as shown in Fig. 7. (The values shown on this chart are selected to show more clearly how a logarithmic scale is constructed; in actual practice the scale would look something like the scale on a slide rule.) Nothing is yet known about line a, except that a straight line drawn across b and c must intersect a at a value given by the equation. Therefore, if a straight line is drawn from 2 on b to 4 on c, and another straight line is drawn from 8 on b to 1 on c, these lines will intersect at 2 on a, thus fixing the position of line a, and giving one value for constructing the scale on this line. If any other line is drawn across a, b, and c, it will give another value on a and from these two values the complete scale may be constructed.

It should be noted that if only the value of the constant k is different, line a will be in the same position, and the values on its scale will simply be moved up or down a certain definite amount. By constructing a chart so that the scale on one of the lines can be moved up and down, any number of equations that differ only in the constant may be solved from the same chart.

In Fig. 7 the product line a falls between the other two because the scales on b and c increase in the same direction. Sometimes it is desirable to have the product line fall outside the other two in order to have a larger scale on the product line. This may be done by simply reversing the direction of the scale on one of the other lines.

Fig. 8 shows a series of alignment charts for the lathe whose analysis appears in Fig. 6. These charts are used in the following way to solve the problem previously calculated from the table. Fig. 8 also shows in tabular form the steps to be taken in solving such a problem.

A straight-edge laid across 8 in. on d and 120 ft. per min. on S gives a spindle speed between 5-b and 1-a. Spindle speed 5-b should be used, and the actual cutting speed is found by moving the straight-edge down on N to 5-b from which S is found to be about 95 ft. per min. It should be noted that in this latter case it is only the position of the straight-edge on line S that is important, not the actual value of S. As in the case of slide rule computations, intermediate values are not important. Advantage is taken of this fact to omit the scales on certain of the lines in Fig 8. It should be understood that all the lines actually have perfectly definite scales, and that certain values of these scales had to be used in constructing the other lines of these charts.

The straight-edge is next laid across lines S, P, and HP to find allowable chip pressure. Line HP carries a scale merely to show the power available at the spindle speed already determined. The straight-edge crosses P above the maximum chip pressure as determined by the strength of the feed mechanism, so this maximum value of P must be used.

The straight-edge is next laid across lines P, C, and A to find the maximum chip area, using the maximum value of P and the value on C for mild

steel. Next the maximum allowable value of F is found by laying the straight-edge across A, D, and F, using the value .25 in. for depth of cut. The next lower available feed of .020 in. per revolution must be used.

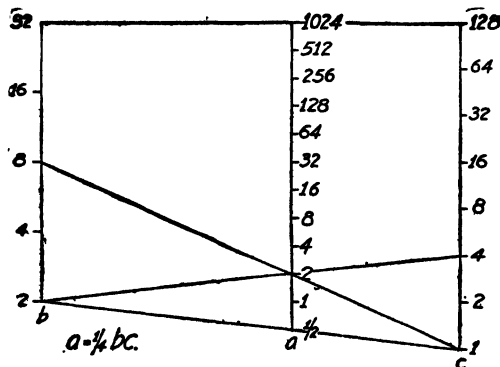



Fig. 7. Construction of Alignment Chart

As formula (9) for cutting time has four variables, two steps are necessary in finding the cutting time from the charts. First find the product of F and N by laying the straight-edge across lines F and N at the points previously found. The required time of about 26 min. is next found by laying the straight-edge across lines FN, L, and T.

SPECIAL SLIDE RULES FOR MACHINE CALCULATIONS.—Special slide rules have been developed for use in machine shops. Some of them are so general that they may be used with any machines of the type for which they are suitable, others are merely adaptations of the alignment charts just described and must be prepared for each machine. Fig. 9 shows a slide rule for finding cutting time of a lathe or boring mill job when the spindle speed, feed, and length of cut are known. These slide rules were developed by Carl G. Barth (Trans. A.S.M.E., vol. 25).

THE MILLING MACHINE.—A somewhat different method of analysis is necessary in the case of a milling machine. Many investigations have been made to determine the power required to remove metal by milling. (See Trans. A.S.M.E., vol. 33, also Am. Mach., vol. 37, and vol. 32, Part I.) It does not seem likely that there is a very definite relationship between power and amount of metal removed for any given material, when such factors as kind of cutter, depth of cut, width of cut, feed, and cutting speed are varied. However, the results of several series of tests indicate that mild steel requires roughly about 2 hp. per cu. in. of metal removed per minute and cast iron roughly one-half as much. These are averages of widely differing values and represent power required by the machine, not power at the cutting tool as was the case in the lathe analysis. Assuming an over-all efficiency for the milling ma-

No.	Given	To Find
1	d S	N
2	HP S	P
3	P C	A
4	A D	F
5	F N	FN
6	FN L	T

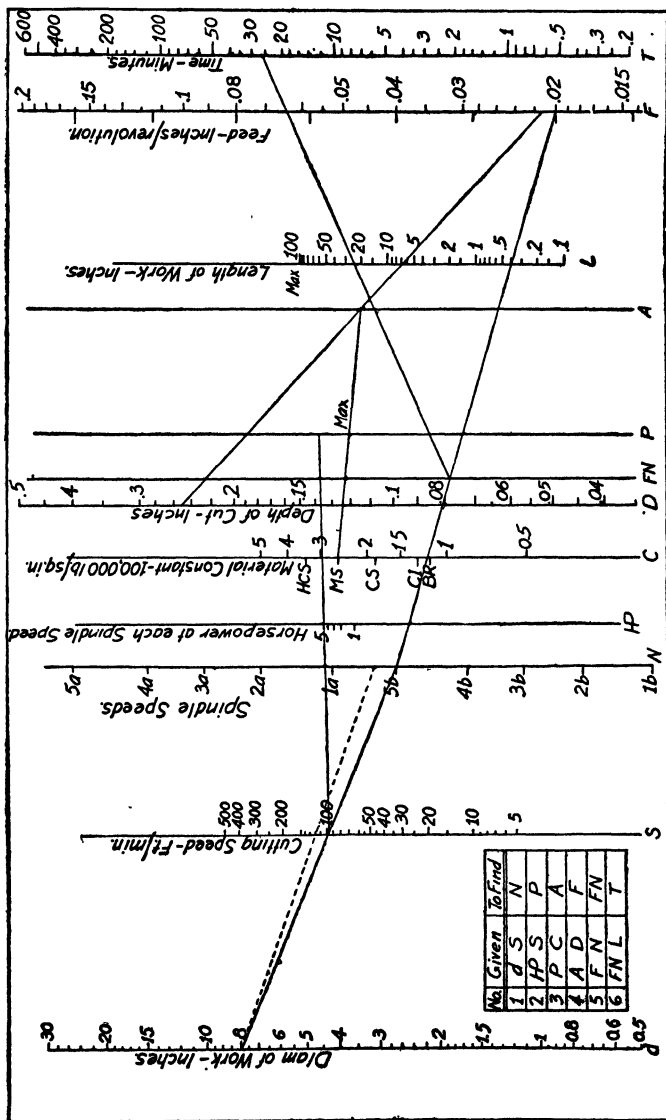



Fig. 8. Series of Alignment Charts for Lathe Analysis

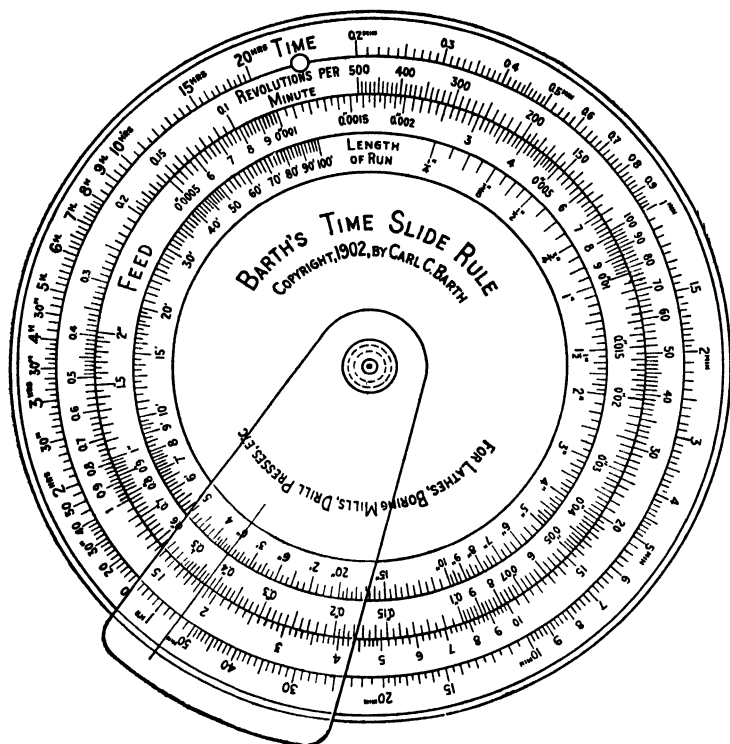



FIG. 9. Barth Time Slide Rule

chine of 75%, power requirements at the cutter would be given by the following formulas:

(10) $\text{hp.} = 1.5AM$ for mild steel

(11) $\text{hp.} = .75AM$ for cast iron

in which A = Area of cut in square inches
M = Table feed in inches per minute

These formulas indicate that roughly twice as much power is required to remove metal at the same rate in milling as with a machine using the lathe-planer type of tool. It should be noted that S is in feet per minute in formulas (2) and (3) and M is in inches per minute in formulas (10) and (11).

A milling machine may be analyzed to determine the power available at milling cutter by methods similar to those used in the analysis of an engine lathe. It is then a simple matter to make up a table to determine

the maximum allowable feed with a given area of cut, and from this table to determine the time required to make the cut. This information is given in Fig. 10.

Cutting speed in milling is the peripheral speed of the cutter. Formula (8) applies in milling as well as in lathe work, except that d is the diameter of the milling cutter in inches, and from this formula maximum spindle speed for a given allowable cutting speed may be determined. The next lower available spindle speed should be used.

The corresponding value of AM may now be used to find the maximum value of M, and from this the maximum value of feed in inches per revolution, the next lower available feed being used. Time required to make the cut may be found from the formula:

$$T = \frac{L}{M} \tag{12}$$

in which T = Time in minutes
L = Length of cut in inches
M = Table feed in inches per minute

It will be noted that in milling neither cutting speed nor spindle speed directly influences the time required to make the cut. To illustrate the use of the table in determining spindle speed, feed, and time required for the milling operation, an example is given.

A cutter with a diameter of 3 in. will be used to take a cut 2 in. wide, 1/8 in. deep and 8 in. long in mild steel. Maximum cutting speed is 80 ft. per min. From formula (8), maximum spindle speed is 102 r.p.m., and, from Fig. 10, 96 r.p.m. should be used. Maximum AM is 1.27, and A is 1/4 in., therefore maximum table feed is 5.1 in. per min., and 5.1 ÷ 96, or .053 in. per revolution of the spindle. From Fig. 10, the next lower available feed is .05 in. per spindle revolution, from which the actual value of M is 4.8 in. per min., and cutting time, by formula (12), is 1.7 min.

MILLING MACHINE — No. M-134

Table working surface: 54 in. x 12 in.
Face of column to harness brace in position: 22 in.
Longitudinal table feed: 34 in. Transverse feed: 11 in.
Vertical feed: 20 in.

Spindle Speeds—Symbol	1-b	2-b	3-b	1-a	2-a	3-a
Spindle Speeds—r.p.m.	32.8	56	96	131	225	385
Horsepower Available at Milling Cutter	1.1	1.4	1.9	1.1	1.4	1.9
Max. *AM* for Steel Cu. in. per min.	.73	.93	1.27	.73	.93	1.27
Max. *AM* for Cast Iron Cu. in. per min.	1.47	1.87	2.53	1.47	1.87	2.53

Longitudinal feeds available, inches per spindle revolution:
.005 – .007 – .010 – .013 – .018
.026 – .036 – .05 – .07 – .10

FIG. 10. Analysis of the Capacity of a Milling Machine

DRILLING.—Drill presses may be analyzed in the same way as other machine tools for power available, strength of feed mechanism, etc.

Complete analysis of a drill press and the resulting table of speeds, feeds, and time required to drill an inch of hole are made more simple because of the fact that only a limited number of drill diameters need be considered. On the other hand, relationships between drill diameter, torque, end thrust, power, speed, and feed are complicated and apparently require formulas with fractional exponents for the variables.

The following analysis is adapted from Hallock, Production Planning, and is based on experiments reported by Dempster Smith and R. Poliakoff before the British Institution of Mechanical Engineers (Am. Mach., vol. 32, Part I). These tests were made with high-speed steel twist drills, drilling cast iron and steel without lubricant. Cast iron was of medium hardness. Steel was Whitworth's fluid-pressed, of medium hardness, .29% carbon and .62% manganese.

Smith and Poliakoff found the following general relationships for torque and end thrust for the materials tested:

(13) $T = 740d^{1.8}F^{.7}$ for cast iron

(14) $T = 1,640d^{1.8}F^{.7}$ for steel

(15) $P = 35,500d^{.7}F^{.75}$ for cast iron

(16) $P = 35,500d^{.7}F^{.6}$ for steel

in which T = Torque in foot-pounds, at drill
P = End thrust in pounds
d = Diameter of drill in inches
F = Feed in inches per revolution of drill

Boston and Oxford gave similar formulas, with somewhat the same exponents for d and F but did not attempt to evaluate the material constants for the different materials used in their tests (Trans. A.S.M.E., vol. 52).

Cutting speed in drilling is the peripheral speed of the drill in feet per minute, and formula (8) applies in drilling also, except that d is diameter of drill in inches. In terms of torque in foot-pounds, **horsepower required at the drill** is given by the formula:

(17) $$\text{hp.} = \frac{2\pi TN}{33,000}$$

in which T = Torque in foot-pounds, at drill
N = Speed of drill in r.p.m.

Substituting the values of T from formulas (13) and (14), the following formulas are obtained:

(18) $\text{hp.} = .141d^{1.8}F^{.7}N$ for cast iron

(19) $\text{hp.} = .312d^{1.8}F^{.7}N$ for steel

Formulas (18) and (19) give the horsepower required to turn the drill. Power is also required to feed the drill, but this is such a small part of the total that it may safely be neglected in determining the power required in drilling.

Formulas for the power required may be still further simplified by substituting in formulas (18) and (19) the value N from formula (8):

(20) $\text{hp.} = .54Sd^{.8}F^{.7}$ for cast iron

(21) $\text{hp.} = 1.2Sd^{.8}F^{.7}$ for steel

For a given drill press, the power available is a constant and for a given material cutting speed is a constant, so that in any actual case the maximum feed may be expressed in terms of drill diameter, by solving formulas (20) and (21) for F:

$$\text{(22)} \qquad \text{Max. } F = \left(\frac{\text{hp.}}{.54S}\right)^{\frac{10}{7}} \times \frac{1}{d^{\frac{8}{7}}} \quad \text{for cast iron}$$

$$\text{(23)} \qquad \text{Max. } F = \left(\frac{\text{hp.}}{1.2S}\right)^{\frac{10}{7}} \times \frac{1}{d^{\frac{8}{7}}} \quad \text{for steel}$$

In the same way formulas (15) and (16) may be solved for F, to obtain the maximum allowable feed, based on the strength of feed mechanism, as follows:

$$\text{(24)} \qquad \text{Max. } F = \left(\frac{P}{35{,}500}\right)^{\frac{4}{3}} \times \frac{1}{d^{\frac{11}{6}}} \quad \text{for cast iron}$$

$$\text{(25)} \qquad \text{Max. } F = \left(\frac{P}{35{,}500}\right)^{\frac{5}{3}} \times \frac{1}{d^{\frac{7}{6}}} \quad \text{for steel}$$

As an example of the use of these formulas, consider a drill press with an available power at the drill of 3 hp., and with a feed mechanism of sufficient strength to take an end thrust of 2,800 lb. Assume a cutting speed of 45 ft. per min. for cast iron and 60 ft. per min. for steel. For this particular machine and these cutting speeds, formulas (22), (23), (24), and (25) simplify as follows:

$$\text{Max. } F = \left(\frac{3}{.54 \times 45}\right)^{\frac{10}{7}} \times \frac{1}{d^{\frac{8}{7}}} = \frac{.050}{d^{\frac{8}{7}}} \quad \text{for cast iron, based on power}$$

$$\text{Max. } F = \left(\frac{3}{1.2 \times 60}\right)^{\frac{10}{7}} \times \frac{1}{d^{\frac{8}{7}}} = \frac{.0107}{d^{\frac{8}{7}}} \quad \text{for steel, based on power}$$

$$\text{Max. } F = \left(\frac{2{,}800}{35{,}500}\right)^{\frac{4}{3}} \times \frac{1}{d^{\frac{11}{6}}} = \frac{.0338}{d^{\frac{11}{6}}} \quad \text{for cast iron, based on feed mechanism}$$

$$\text{Max. } F = \left(\frac{2{,}800}{35{,}500}\right)^{\frac{5}{3}} \times \frac{1}{d^{\frac{7}{6}}} = \frac{.0145}{d^{\frac{7}{6}}} \quad \text{for steel, based on feed mechanism}$$

These last four equations are plotted in Figs. 11 and 12, for cast iron and steel respectively, and a third curve added to each which shows the maximum feed based on the twisting strength of the drill, this curve being taken directly from Hallock, who states that it was taken from the results of the tests made by the Loewe Co. on drills of different diameters. These three curves show the maximum feed for a given diameter of drill, based on power available, strength of feed mechanism, and twisting strength of drill.

The lowest curve at any diameter gives the maximum feed for that size of drill, and the actual feed should be the next lower feed available on the machine. This particular machine has available spindle speeds of 40, 56, 80, 112, 160, 225, 320, 450, and 640 r.p.m., and feeds of .004, .005,

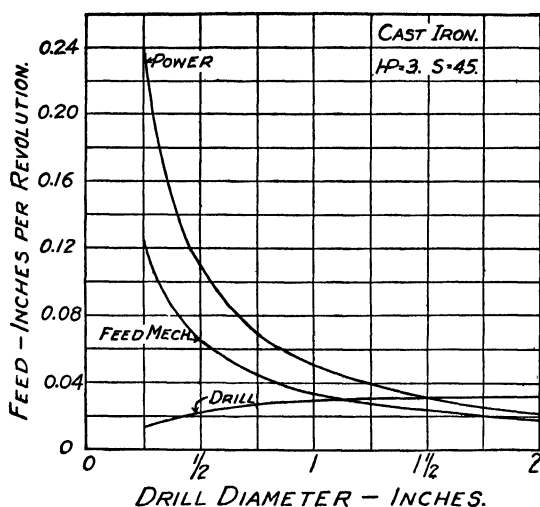



FIG. 11. Chart of Feed of Drills in Cast Iron

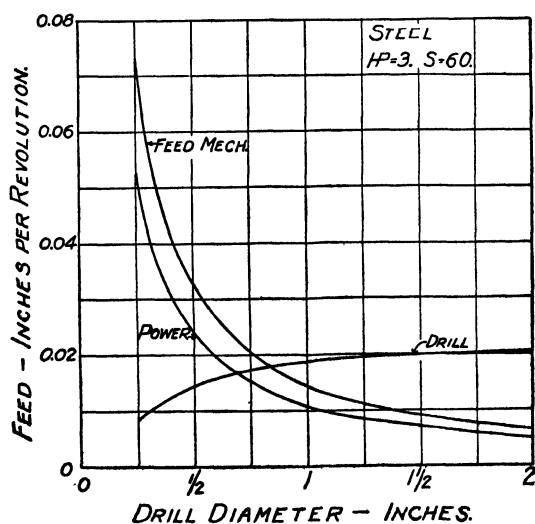



FIG. 12. Chart of Feed of Drills in Steel

SLIDING HEAD DRILL PRESS — No. D–73

Actual swing: 24½ in.
Diameter of table: 21½ in.
Vertical traverse of spindle: 10½ in.

Max. distance spindle to table: 35½ in.
Max. distance spindle to base: 52½ in.
Traverse of table on column: 13 in.

FOR CAST IRON

d	¼	⅜	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1¾	2
F	.012	.016	.020	.025	.025	.025	.025	.030	.025	.025	.020	.020	.020	.016
N	640	450	320	225	225	160	160	160	112	112	112	112	80	80
NF	7.7	7.2	6.4	5.6	5.6	4.0	4.0	4.8	2.8	2.8	2.2	2.2	1.6	1.3
h	.07	.11	.14	.18	.22	.25	.29	.32	.36	.40	.43	.47	.50	.58

FOR STEEL

d	¼	⅜	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1¾	2
F	.008	.012	.014	.016	.014	.012	.010	.008	.008	.007	.006	.006	.006	.005
N	640	450	450	320	320	225	225	160	160	160	160	112	112	112
NF	5.1	5.4	6.3	5.1	4.5	2.7	2.3	1.3	1.3	1.1	.96	.67	.67	.56

d = Drill diameter in inches
N = Spindle speed in r.p.m.
F = Spindle feed in inches per spindle revolution
NF = Spindle feed in inches per minute
h = Cone height of drill in inches

FIG. 13. Analysis of the Capacity of a 24-in. Drill Press

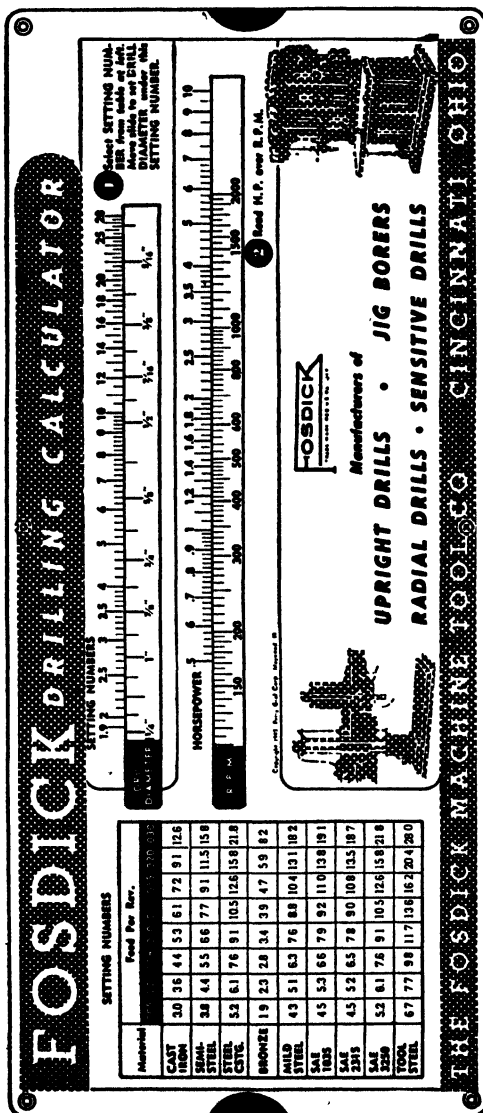



Fig. 14a. Slide Rule for Drilling Calculations

FIG. 14b. Reverse of Fig. 14a.

.006, .007, .008, .010, .012, .014, .016, .020, .025, and .030 in. per spindle revolution.

Fig. 13 shows, for this particular drill press, the proper spindle speed for each drill diameter, for cast iron and steel, based on the allowable cutting speed for each material; also the proper feed, taken from Figs. 11 and 12. The product of spindle speed and feed gives the axial travel NF of the drill in inches per minute. This is also shown in Fig. 13. The cone height of the drill is also given in the table because drilling begins with the contact of drill point and work and ends when the drill cone emerges completely from the hole.

The time required to drill through any thickness of material is given by the formula:

$$T = \frac{L + h}{NF} \tag{26}$$

in which T = Time in minutes
L = Thickness of work in inches
h = Cone height of drill in inches
N = Speed of drill in r.p.m.
F = Feed of drill in inches per revolution

A convenient slide rule for determining the surface speed, feed per revolution, and time for drilling with drills of the various diameters has been developed by the Fosdick Machine Tool Co., and is illustrated in Figs. 14a and 14b.

Additional Factors

OTHER FEATURES IN MACHINERY SELECTION.—The preceding discussions have dealt with two aspects of machinery selection and replacement: (1) economic return on the investment, and (2) determination of machine tool capacity as a factor in production planning. Other machine factors also enter into the problem as influencing continuity of operation. Among them are (1) rigidity and strength of design and construction, (2) availability of the high cutting speeds required for cemented-carbide tools, and (3) means of lubrication. While an elaboration of these features is outside the scope of this Section, the third will be discussed in brief.

LUBRICATION OF MANUFACTURING MACHINERY.—The aim in machinery lubrication should be to attain conditions of fluid friction instead of solid friction. Laws of fluid friction are quite different from those applying to solid friction. The following tabulation gives coefficients of friction for several conditions.

Coefficient of Friction

Solid friction	.1 to .4	
Semi-lubricated	.01 to .04	average .03
Fluid friction	.002 to .01	average .006
Roller bearings	.002 to .007	
Ball bearings	.001 to .003	

Fig. 15, by Clower (Mill & Factory, vol. 19), gives the characteristics of the oiling systems commonly used on machinery.

System	Type of Service	Characteristics
HAND OILING	Low-speed bearings, open gears, chains, wire rope, etc., of relatively cheap and rough machinery.	Nonautomatic, unreliable, very inefficient. First cost low, but maintenance usually high.
DROP FEED OILING	Plain anti-friction bearings, chains, gears, etc. Commonly used on steam engines, air ammonia compressors, internal combustion engines, machine tools, etc.	Nonautomatic, irregular, reliable, adjustable to certain degree, relatively cheap.
WICK FEED OILING	Paper mill, rubber mill, woodworking, ceramic plant machinery, railway truck axles, small electric motors, general bearings, etc.	Nonautomatic, irregular, reliable, adjustable, moderately efficient, relatively cheap.
BOTTLE OILING	Plain horizontal bearings of small or medium size machine tools, shafting in textile mills, conveyor shaft bearings, blowers, etc.	Automatic, adjustable, reliable, regular, moderately efficient, and cheap. Cannot be used where glass bottles will be broken.
RING CHAIN AND COLLAR OILING	Electric motors, fans, blowers, centrifugal pumps, steam engines, line shaft bearings, etc.	Automatic, reliable, efficient, regular, clean, minimum attention. Limited to horizontal bearings.
BATH OILING	Enclosed gears, chains, wire cables, plain and anti-friction bearings, thrust bearings, etc.	Automatic, efficient, reliable, regular, minimum attention. Require oil-tight housing, high first cost, limited application.
SPLASH OILING	Bearings grouped in oil-tight housings, enclosed gears of all types, crosshead pins, guides of steam engines, compressors, internal combustion engines.	Automatic, efficient, reliable, regular, limited application. Oil must be maintained at constant level.
CIRCULATION OILING	High-speed, heavily loaded bearings, high-grade gearing of all types, machine tools, steel mill machinery, steam turbines, fans, blowers, etc.	Usually automatic, reliable, positive, regular, adjustable, efficient, wide range of application. First cost high.

FIG. 15. Oiling Systems and Their Characteristics

SECTION 13

TOOLS, JIGS AND FIXTURES

CONTENTS

SECTION 13

TOOLS, JIGS AND FIXTURES

DEFINITIONS.—The discussion in this Section covers the small tools commonly used in the mechanical industries, from the standpoint of their planning, economic factors, classification, storage and issue, inspection and reconditioning, and such essential elements of tool engineering in regard to the common varieties of tooling as would be of concern to a production engineer. It does not include operating implements, such as shovels, hoists, etc., or any machines, which are often called machine tools. It does cover gages, which are frequently carried in the tool cribs. The designation "tool" also includes dies, jigs, and fixtures.

The various devices in the category of tools may be defined as follows:

Tool, any small appliance used in doing work on materials, parts, or products.
Jig, a tool that clamps the work and guides other tools in performing cutting operations.
Fixture, a tool that holds work while machining operations are being performed on it.
Die, a tool used in a press for the blanking, forming, shearing, cutting, or perforating of materials. Also a mold in which materials such as plastics or soft or molten metals are formed usually under pressure.
Mandrel, a shaft or spindle for holding bored parts while the outside surfaces are being turned in a lathe.
Arbor, a spindle that holds cutting tools while they are performing an operation, for example, a milling cutter arbor.
Collets, sleeves, sockets, tools that have nearly identical functions, and serve as adaptation tools for cutter shanks, milling arbors, drills, taps, and reamers.
Gage, a device used as a standard by which to check the accuracy of work.
External gage, one for checking outside diameters or surfaces.
Internal gage, one for checking inside diameters or surfaces.
Toolroom or tool department, place where tools are made (and sometimes also designed).
Tool crib or tool storage, place where tools are stored, and issued to and returned from jobs.

GENERAL CLASSES OF TOOLS.—In Fig. 1 is given the fundamentally accepted Taylor method, as adapted by Gilbreth, for classifying tools according to nature and uses in the wide range of metal-working plants. This classification, with its letter symbols, can form the basis for designations and also for the arrangement of tools in storage, but further breakdown is obviously necessary for definite distinction of subgroups and individual tools.

Companies engaged in many kinds of industries, such as chemical, ceramic, refining, paper-making, or other processing plants, and plants making textiles, clothing, etc., will have a minimum of the above kinds of tools, which are used mostly in maintenance work, but they will have a variety of special tools for their own kinds of production.

General Tool Groups

Group	Description
A – Abrading Tools 0000–0049	All tools for filing, grinding, scratching, scraping, etc.
B – Blanking Tools 0050–0099	All tools for blanking, bending, drawing, flattening, piercing, shearing, swedging, and trimming.
C – Clamps and Holders 0100–0199	Devices of all kinds, including bolts, nuts, screws, and washers for holding work.
D – Drilling and Boring Tools 0200–0299	All tools that remove metal from interior, including drills, boring bars, cutters, lathe boring tools, reamers, taps, and holding devices for this class.
F – Heating and Lighting Tools 0300–0349	All tools used for melting, molding, tempering, and annealing.
H – Hammers 0350–0399	All tools that work by striking or being struck.
J – Jigs, Fixtures, and Templates 0400–0499	All instruments for duplicating work.
M – Measuring Devices 0500–0599	All gages and instruments of precision.
P – Paring Tools 0600–0699	All tools that remove chips from surfaces by cutting (except slotting and milling tools).
R – Revolving Cutters 0700–0749	Including milling cutters, gear hobs, circular saws, etc., and holding devices for this class.
S – Slotting Tools, etc. 0750–0799	Including hack saw and slotting machine tools.
T – Transportation Tools 0800–0899	All tools used in moving materials, etc.
W – Wrenches 0900–0949	All hand tools causing rotation, except die holders and tap wrenches.
Z – Special or Miscellaneous Tools 0950–0999	

Fig. 1. General Tool Classes (Taylor classification adapted by Gilbreth)

Tooling Procedures

STEPS IN TOOLING.—When planning tools for the work to be done, a number of steps are taken. Some of the steps are technical, others are matters of operation of the system of tool control:

1. Obtain data on parts or products to be manufactured and materials to be used (from production programs, orders, drawings, bills of material, specifications, quantities of products to be made). The initiative in assembling and analyzing these data for the purpose of tooling rests basically with the methods engineer.
2. Decide on methods of processing (equipment to be used, operations and their sequence, tools to be used). The tool factor depends upon equipment, operations, and quantities of products to be manufactured. The methods engineer, operation list writer, head of the tool design section, designer of the product, a representative of the operating or manufacturing department, and sometimes the chief inspector may confer or be consulted on processing methods, to coordinate design, tooling, production control, and manufacturing into a practical, workable program. Such matters cannot be handled by one unit alone, or by each one on a separate basis.
3. Determine the economy of obtaining and using any special tools which may be applied to the work. Coordination among departments on this point may be necessary as in item 2.
4. Have a regular plan of stocking standard and generally used tools, in proper quantities, keeping them in repair, and replacing them when necessary, so that no special check is necessary on such tools. Maintain a record and index system for all such tools. The index and perpetual inventory record of tools would be carried in the production control department, accessible to the methods engineer and others concerned with such information. Duplicates in modified form would be necessary in the tool crib.
5. Have a central index and record of all special tools previously made and on hand so that repeat jobs can be planned and run without difficulty, or new jobs may be laid out to fit in with such tooling. Check on such tools where necessary. Both the methods engineer and the tool crib need such records and indexes and they may be helpful in the tool design and engineering departments.
6. Determine the specific nature of any new special tools that it may be found economical to obtain and use. Decide whether to buy or make them. This point usually will be covered by agreement among the same departments mentioned in items 2 and 3.
7. Prepare drawings, descriptions, specifications, etc., for these special tools. If the plant itself manufactures tools these data will be developed in the tool designing section or by qualified men in the regular engineering department. Make sure that designs are practical and economical from the operating viewpoint.
8. Order the tools. Follow up on orders. If the tools are made inside the plant, the toolroom or tool department will produce them. Ordering and follow-up will be done by the production control department.
9. Check the tools upon delivery to see that all requirements are met and all dimensions are correct. In special cases try them on the work before acceptance. This step would be under the direction of production control, but a representative of the operating department using the tool, and perhaps an inspector, would often aid in the check and test.
10. Make out the proper records, with full descriptions, quantity of the tools received, cost, and tool crib location. File copies in the central tool index, other copies in the tool cribs. This work would be done in the production control department.
11. Provide an adequate system for issuing all tools and for receiving back all those not permanently issued to jobs. Production control, or the operating department, would regulate this work, whichever has direction of the tool crib.
12. Adopt standard methods for inspecting tools after (and sometimes

during) use to have them adjusted, repaired, sharpened, etc., before putting back into storage. Provide for replacements of frequently used tools that become damaged or worn. This work would be done in the tool cribs under the direction of production control, or of the operating department if the tool crib is under its jurisdiction.

13. Establish a proper plan of charging off the costs of the various tools, either to jobs or as expense items. The accounting and cost accounting departments would regulate this procedure although the basic data would come through production control, and entries should be made on the tool record cards.
14. Check the tools inventories at least annually to see if proper quantities, but not excesses, of the various kinds of generally used tools are carried. Decide whether to keep or scrap tools for which there has been no demand over a long period. Production control would carry on these investigations, in cooperation with the operating department, and perhaps consultation with engineering, tool design, and sales.

These activities will be covered in the following discussion, wherever elaboration is necessary.

ESSENTIAL REQUIREMENTS OF TOOL CONTROL.—There are certain essentials for tool control as outlined by Cornell (Organization and Management):

1. All tools which have to be made for jobs should be designed by the tool design section.
2. Tools needed for each operation should be specified.
3. Tools should be standardized.
4. A toolroom or rooms should be maintained.
5. Tools should be inspected and maintained in proper condition.
6. Tools should be delivered promptly to the workers when and where required.
7. All tools should be fully accounted for and their exact location known at all times.
8. Workmen should be held responsible for all tools used by them.
9. Personnel of the tool crib should be carefully selected.
10. Records should be kept showing performance and tool cost.
11. A perpetual inventory of tools should be provided.

ADVANTAGES OF TOOL CONTROL.—There are important advantages resulting from the establishment of organized procedures for tool control, as made evident by the above outline of steps in tooling and the requirements of control. Cornell states these advantages (here slightly adapted) as follows:

1. Reduced capital tied up in inventory, and less interest charges. Tool stocks are kept consistent with production requirements. New tools are not designed and made when proper tools already exist. Obsolete tools are disposed of.
2. Quality of product is maintained. Good tools permit of good workmanship.
3. Production cost is reduced. Work is turned out in less time with less scrap and spoilage.
4. Tool cost is reduced. Proper care prolongs tool life. Worn tools are salvaged. Losses due to waste and pilferage are cut down.
5. Production control is aided. Availability of standard stocked tools and procurement of new or special tools is taken care of before work

is ready to go into production. Planning can be done with assurance of meeting schedules.

6. Tool storage space is conserved and tool crib operating cost is reduced. Centralization, orderly arrangement, proper shelving, adequate indexes and records, capable personnel, all contribute toward such economies.

Economic Factors in Tooling

BASIC PROBLEMS.—The first and most important element to consider in connection with small tools is that of economic results. A certain expenditure for tools is advantageous wherever parts are to be produced in quantity. How much capital should be put into small and special tools depends on the immediate situation. Too often money is tied up in jigs, fixtures, and other tools which show a substantial saving when in use, but they are used so seldom that they do not pay. It is evident that a saving of 10% of labor cost on a regular job might justify a greater expense for tools than a saving of 90% on a small job which may be made only once or twice a year. Other factors besides saving in time and labor expense which must be considered are expected life of the fixtures and possible discontinuance of the article which they produce. The controlling factor in producing small tools is the economic advantage due to lower labor cost. Other considerations, however, are important, such as improved, duplicate, or interchangeable parts, increased accuracy, and ability to use lower-priced labor in production. When any one of these latter reasons indicates the necessity for a special tool, lower labor costs are an accompanying advantage.

Charles J. Stilwell, President of The Warner & Swasey Co., gives a classification of tools from the cost point of view which is very useful in recognizing economic differences. He states:

Tooling is an important item. Tools for use on machines are expensive and frequently cost as much as the entire machine on which they are employed. They may be usable but one year or one season, depending on the product to be manufactured. There are three kinds of tools generally used:

1. **Standard tools**—which are those that may be used interchangeably from one machine to another, as tooling layouts are altered. The usual safe depreciation period is two years, or thereabouts.
2. **Special tools**—frequently very expensive, bearing high relation to the cost of the machine itself, and applicable to only one job, model, or product. They often have a depreciation of 100%, for the usable period of one year, one season, or one model.
3. **Perishable tools**—these should not be overlooked because in many cases they involve outlays of considerable sums over the period of a year's time.

ECONOMY OF JIGS AND FIXTURES.—Roe (Principles of Jig and Fixture Practice, revised in Mech. Eng., vol. 63, originally published in Trans. A.S.M.E. MSP–51–11) developed a group of simple formulas to be used in determining the economic results from the use of jigs and fixtures. He states that the economy problem involved in any situation centers around one or more of the following questions:

1. How many pieces must be run to pay for a fixture of given estimated cost to show a given estimated saving in direct labor cost per piece? For instance, how low a run will justify a fixture costing $400 to save 3 cents on direct labor cost of each piece?
2. How much may a fixture cost which will show a given estimated unit saving in direct labor cost on a given number of pieces? For instance, how much can be put into a fixture to "break even" on a run of 10,000 pieces, if the fixture can save 3 cents on direct labor cost of each piece?
3. How long will it take a proposed fixture, under given conditions, to pay for itself, carrying its fixed charges while so doing? For instance, how long will it take a fixture costing $400 to pay for itself if it saves 3 cents on direct labor cost per unit, production being at a given rate?

Questions 1, 2 and 3 assume that savings just balance the expense. There is another practical question:

4. What profit will be earned by a fixture of a given cost, for an estimated unit saving in direct labor cost and given output? For instance, what will be the profit on a $200 fixture if it will save in direct labor cost 3 cents a piece on 10,000 pieces?

These questions involve something more than simple arithmetic for an answer. While the credit items for the fixture depend mainly on the number of pieces machined, the debit items involve time and number of set-ups required, i.e., whether pieces are run off continuously or in a number of runs.

FORMULAS FOR JIGS AND FIXTURES.—Roe developed his formulas for jigs and fixtures from general equations for the efficiency of equipment formulated by the Materials Handling Division of the American Society of Mechanical Engineers. These equations provide a basis for the economic analysis of industrial equipment, and for the determination of probable profit on any proposed installation for a given situation and cost of performance. They take into account interest, depreciation, obsolescence, and other items of overhead. They can be used with modifications and simplifications for tool equipment. These modifications Roe has made. Certain factors in materials handling formulas are important in installations in that field, but are of less importance in dealing with fixtures and may be dropped entirely. Other factors, such as interest rate, taxes, and the like, may be taken as a constant and brought together.

Roe originally presented nine formulas which have since been reduced to four simple and workable forms designated as (1), (2), (3), (4) by leaving out factors for power cost, unamortized value of equipment displaced (less its scrap value), and savings through increased production, which are small values. His symbolization is on the following page.

To be of practical value the formulas should be as simple as possible and yet reflect essential conditions, and should be easily applied. Equations (1), (2), (3), and (4) meet this condition for most fixtures. They take into account number of pieces manufactured, saving in unit labor cost, overhead on labor saved, the cost and frequency of set-ups, interest on investment, taxes, insurance, upkeep, and depreciation.

In using formulas it must be remembered that N is the number of pieces manufactured in a **year**, not per run, except for the case of a single run of less than one year's duration.

Let N = Number of pieces manufactured per year

Debit Factors:

A = Yearly percentage allowance for interest on investment. Either original cost or depreciated value of investment may be used.
B = Yearly percentage allowance for such fixed charges as insurance, taxes, etc.
C = Yearly percentage allowance for upkeep
$1/H$ = Yearly percentage allowance for depreciation and obsolescence on the basis of uniform depreciation, where H is the number of years required for amortization of investment out of earnings
I = Estimated cost of the equipment or fixture, i.e., cost installed and ready to run, including drafting and toolroom time, material and toolroom overhead, in dollars
Y = Yearly cost of set-ups, in dollars. This value should include expense for taking down the apparatus and putting machine into normal condition.

Credit Factors:

S = Yearly total saving in direct cost of labor, in dollars
= Ns, where
s = Savings in unit labor cost
T = Yearly total saving in labor overhead, in dollars
= St, where
t = Percentage of overhead on the labor saved
V = Yearly gross operating profit, in excess of fixed charges, in dollars

To "break even," the yearly operating savings equal total fixed charges per year.

$$N = \frac{I\left(A + B + C + \frac{1}{H}\right) + Y}{s(1 + t)} \tag{1}$$

$$I = \frac{Ns(1 + t) - Y}{A + B + C + \frac{1}{H}} \tag{2}$$

$$V = (Ns)(1 + t) - Y - I\left(A + B + C + \frac{1}{H}\right) \tag{3}$$

$$H = \frac{I}{Ns(1 + t) - Y - I(A + B + C)} \tag{4}$$

Items A, B, and C, once settled upon, need change little. If the plant has the practice of requiring new equipment to pay for itself in a definite time H, say 2 years, depreciation $1/H$ may be added to the other carrying charges, making a single percentage factor for the term $(A + B + C + 1/H)$ which can be used until management deems that changed conditions require modification.

EXAMPLES OF FIXTURE ECONOMY ANALYSIS.—To illustrate the economy analysis of a fixture using Roe's formulas, eight examples are worked out below. These are adapted from his paper, assuming the following data:

s = Estimated unit saving in direct labor cost	= 3 cents	A = Interest rate	= 6%
t = Percentage overhead on labor saved	= 50%	B = Fixed charges rate	= 4%
Y = Estimated cost of each set-up	= $10	C = Upkeep rate	= 10%
		H = Equipment life, est'd	= 2 years
		$1/H$	= 50%
		$A + B + C + 1/H$	= 70%

1. If estimated cost, I, of a fixture is $400, how many pieces must be put through each year, in one run, or lot, per year, to return cost out of earnings in 2 years?

From formula (1),

$$N = \frac{\$400 \times .70 + \$10}{\$.03 \times 1.5} = 6{,}450 \text{ pieces}$$

That is, if a $400 fixture is to pay for itself in 2 years and carry overhead, with a single run per year, 6,450 pieces must be put through each year.

2. If pieces are put through in 6 runs, or lots, per year, how many pieces must be made per year to return cost out of earnings in 2 years?

Using formula (1),

$$N = \frac{\$400 \times .70 + \$60}{\$.03 \times 1.5} = 7{,}550 \text{ pieces}$$

Obviously more pieces must be run per year if the number of set-ups is increased. There is, of course, a breaking point where it pays to have multiple runs, even at a higher production cost per piece, due to balancing of production costs and fixed charges on increased inventory.

3. If fixture is to return its cost in a single run, how large must that run be?

Turning to formula (1), in this case H is unity as the fixture must pay for itself within the year.

$$A + B + C + 1/H = 6\% + 4\% + 10\% + 100\% = 120\%$$

$$\text{Then } N = \frac{\$400 \times 1.20 + \$10}{\$.03 \times 1.5} = 10{,}900 \text{ pieces}$$

This analysis shows that a smaller total output is required than when 6,450 pieces are made per year for each of 2 years, or 12,900 in all. This is due to one less set-up and carrying overhead for only 1 year instead of 2. It will be noted that this example assumes the full year values for A, B, and C. If the run is short and it is felt this is too drastic, the values can be cut down in the proportion of the actual running time to one year. It is safer, and therefore good practice, to use yearly rates, as the time for complete turnover of money going into the fixture is hard to determine and certainly is longer than the run itself. Cost of short-lived equipment should be extinguished as soon as possible.

4. How much money can be invested in a fixture for a single run of 10,900 pieces at an estimated saving of 3 cents per piece?

From formula (2),

$$I = \frac{10{,}900 \times (\$.03 \times 1.5) - \$10}{1.20} = \$400$$

5. How much money can be invested in a fixture that is to produce 7,550 pieces per year in 6 runs, if saving per piece is 3 cents, and if cost of fixture must be returned in 2 years?

From formula (2),

$$I = \frac{7{,}550 \times (\$.03 \times 1.5) - \$60}{.70} = \$400$$

6. In how long a time will a fixture costing $400 pay for itself under the conditions of example 5?

From formula (4),

$$H = \frac{\$400}{7{,}550 \times (\$.03 \times 1.5) - \$60 - \$400 \times .20} = 2 \text{ years}$$

Example 5 shows that break-even is at a cost of $400.

7. If a fixture to meet the conditions of Example 6 can be made at a cost of $250 instead of $400, what would be the profit?

Using formula (3) for 7,550 pieces per year in 6 runs per year,

$$V = 7{,}550 \times (\$.03 \times 1.5) - \$60 - \$250 \times .70 = \$105 \text{ per year}$$

For a single run of 10,900 pieces the profit would be,

$$V = 10{,}900 \times (\$.03 \times 1.5) - \$10 - \$250 \times 1.20 = \$180.50$$

8. How much money can be put into a fixture for a single run of 2,000 pieces under the conditions of the preceding examples: (a) If fixture will save 3 cents per piece with a set-up cost of $10? (b) If fixture will save 5 cents per piece with a set-up cost of $15?

From formula (2),

$$\text{For (a)}, I = \frac{2{,}000 \times (\$.03 \times 1.5) - \$10}{1.20} = \$66.66$$

$$\text{For (b)}, I = \frac{2{,}000 \times (\$.05 \times 1.5) - \$15}{1.20} = \$112.50$$

The above examples show how economy formulas help in deciding tooling-up problems as they arise. They apply not only to jigs and fixtures but also to punches and dies, special tool equipment, and, in fuller forms, to machine tools.

It is recommended that in authorizing expenditures for all fixtures and tools above some established minimum cost, an estimate be made of

1. Cost of the fixture.
2. Output of the fixture.
3. Profit or saving from it.

When it is put into operation, the actual results should be checked with these estimates.

Such a procedure will give a check on quality of tool designing. If tool costs are overrunning estimates and output and savings are falling short, the facts will be shown up. If tool work is good, the management will know it, and have means for measuring the profit obtained.

PURCHASING VERSUS MAKING TOOLS.—Price and service generally decide whether a certain tool is to be purchased or made in the factory. Standard tools that can be purchased in the open market,

and can usually be bought more cheaply, are of a quality to give better service than those made in the factory's toolroom. In deciding upon the advisability of purchasing or of making, the following points should be considered:

1. **Cost of making versus buying tools.** Care should be taken to consider all elements of cost in manufacturing tools, including overhead. Toolrooms, as a rule, do not have overhead applied, since they are rated as nonproductive. The fact remains, however, that power is absorbed, machines and tools worn out, floor area occupied, and light supplied in the toolroom as well as in any other shop, whether these items are charged to the cost of making tools or not.

2. **Tool breakage due to poor workmanship,** wrong dimensions, flaws in the steel, and improper hardening, is rather high. Replacement of tools thus damaged is done without cost by all reputable tool manufacturers. On the other hand, when a factory manufactures its own tools, breakages from the above causes are nonrecoverable losses.

3. Closely connected with the original cost of production is **the service a tool gives.** A tap that costs 50% more to purchase than to make should thread 50% more holes in order to justify the additional cost. But if it produces 100% or even 75% more holes, then the purchased tap would be the more economical. As a rule, tools that can be made on a productive basis by tool manufacturers should be closely investigated before any attempt is made to produce them in preference to buying them. However, special tools that have to be manufactured on a special order by an outside firm can often be made cheaper by the factory itself.

PERFORMANCE RECORDS.—Tests of tools should be correctly conducted. The nature of the tests should be such as to give an adequate trial and to yield essential facts. Careful record of performance of all such tools should be kept for the purpose of determining whether or not tools of the same kind are to be put into general use. To aid systematic tool development, good records are needed both for the performance and cost of maintenance on each class of tools.

STANDARDIZING ON VARIETY CARRIED.—Principles of standardization as applied to machine parts are also applicable to small and special tools. Standardization of tools is an item of importance increasing with the size and diversity of an industry. Standardization implies the adoption of tools and equipment of a kind as produced by one manufacturer rather than by several. It presupposes, however, that, prior to the selection of any given make, exhaustive tests under service conditions have been made to eliminate any that would not meet requirements.

Advantages of standardization are:

1. Reduction in purchase prices because of larger purchases of a given item.
2. Reduction in spare parts stores.
3. Reduction in storage space.
4. Reduction in clerical work.

Where two or more plants of the same company operate on the same standard tools and equipment, each plant can maintain smaller inven-

tories of replacement parts, and, should a shortage of an item occur in one plant, a telephone call to the other plant will assure a more prompt delivery of the desired part than were it necessary to order the part from the manufacturer.

In establishing tool and equipment standards, however, care should be taken that they do not become too rigidly established, to the exclusion of newer tools more highly developed or more economical to operate. Toolroom records of tool maintenance should be frequently consulted in establishing standards. Such records will readily indicate what tools require the most servicing, and thus suggest the order of making studies on tools to be competitively tested when standards are to be adopted.

Tool Classification

FUNDAMENTALS OF CLASSIFICATION.—Tools should be classified according to the purpose for which they are used. Each class should have a descriptive symbol which completely identifies it and separates it from other classes, types, and sizes.

Advantages of classification and symbolization of tools are: (1) identification; (2) facilitation of storage and issue; (3) brevity and conciseness in making records.

Classification by Likeness.—Tools may be classified by putting into each group the varieties of a general class. For example, various kinds of drills or of wrenches may be put together.

KINDS OF DRILLS

Twist	Hollow	Shell
Ratchet	Flat	Jobbers or machinists
Straightway or farmer	Wire	Hog nose
	Oil groove	Chucking

VARIETIES OF MACHINE WRENCHES

Box tool-post	Pin spanner
Chuck	S-wrench
Double-end	Set screw
15° angle	Single-end
Hook spanner	Socket
Pin face	22½° angle

Classification by Function.—Another form of classification is by use or function. Fig. 1 gives general tool classes developed for machine shops by Frederick W. Taylor, together with the letter symbol for each class.

IDENTIFICATION OF TOOLS.—There are five systems under which tools may be identified, but only three of those systems, 1, 2, and 4, below, are in general use:

1. Straight numeric system where tools are numbered in sequence in a series, these numbers being put on the tools themselves and on the drawings as well.

2. Classified numeric system best represented by the Dewey Decimal system.
3. Straight letter system.
4. Mnemonic system where a combination of letters is suggestive of the tool symbols.
5. Combinations of letters and numbers.

There are many varieties of these systems. It is good practice to use the same system also for jigs, fixtures, and gages for uniformity in identifying all tools and devices for any given job.

NUMERIC SYSTEMS.—The numeric systems have advantages. They need no elaborate explanation, are condensed, have no complicated structure, and are direct. In many cases the accounts of a company are classified under a numeric system, so a large number of the staff are familiar with the principles of such a method. There are disadvantages, however, associated with this plan, as will be shown.

Straight Numeric System.—The straight numbering method consists of running a series of consecutive numbers for all special tools (Christensen, Tool Control). Generally such tools as drills, taps, and reamers are specified by their names. An index is kept of these numbers which gives information as to the nature of the tool and operation for which it was designed. This system, in spite of its general use, has inherent disadvantages.

First, it is impracticable to keep tools in the crib by number, because two consecutive numbers may, and usually do, represent tools of a very different nature and size. Many attempts have been made to make straight numbering system more efficient. One method is that of placing tool numbers on drawings. When a certain drawing is given to a workman, he has only to list the numbers of tools needed for the particular operation he is to perform from the drawing and then present this list to the tool crib for the necessary tools. However, the crib attendant must consult his index in order to determine what the tools are. This step takes time while perhaps a high-priced machine is standing idle.

(Applied to General Classes of Tools)

1. Sharp-edge Tools	All tools that work by cutting off material, except chisels and blanking tools.
2. Measuring Devices	All gages and instruments of precision.
3. Jigs and Fixtures	All tools used for duplicating work such as jigs, fixtures, etc.
4. Impact Tools	All tools that work by impact, including chisels, hammers, etc.
5. Wrenches	All tools that work by causing rotation.
6. Holding Tools	Clamps of all kinds, mandrels, nuts, dogs, etc.
7. Fire Tools	All tools that are used for melting, heating, welding, etc.
8. Transportation Tools	All tools that are used in moving materials.
9. Miscellaneous	All tools not otherwise classified.

FIG. 2. Numerical Tool Classification Key Sheet—Dewey Decimal System

In the second place, it is almost an impossible task to keep drawings up to date. For example, reamer No. 6875 may be satisfactory when a certain job is being done on a plain engine lathe. If the shop finds it is more advantageous to do the work on a hand-screw machine, the shank of the reamer must be changed, so a new reamer is made and its number is different, say, No. 7165. In a few weeks or months, the shop finds that a further reduction can be made by doing the work on a four-spindle automatic. Again the reamer must have a different shank; therefore, a new reamer and another number are selected which necessarily call for another change in the drawing. On a job where the method of machining is changed so often, many erasures and mistakes are likely to occur on the master drawing. Cases like the above happen so frequently that the task of keeping drawings up to date is almost impossible.

Classified Numeric System.—In the classified numeric system, or Dewey Decimal system, certain digits, generally the first nine, represent the class of tools. Fig. 2 gives the numeric key sheet for the system applied to general classes of tools (Christensen).

Each group may be subdivided indefinitely. To illustrate, a further division of the sharp-edged tools follows:

1.1 – Drills
1.11 – Twist drills
1.112 – Taper shank twist drills
1.1123 – High-speed twist drills with taper shanks
1.11234 – High-speed taper shank twist drills of standard length
1.2 – Taps
1.21 – U. S. Standard taps
1.212 – U. S. Standard taps with machine shanks
1.2123 – U. S. Standard high-speed taps with machine shanks

Simply by continuing to add digits to the key number, it is possible to classify tools to as small a variable difference as is desired. The difficulty is that only ten variables can be provided for in any given division. Clearly this is not sufficient to care for all the classes of tools in many general groups: for example, tools that have cutting edges cannot be divided practicably into ten divisions, i.e., drills, taps, reamers, counterborers, countersinks, milling cutters, hack saws, thread-cutting dies, lathe tools, and a great many others.

Another difficulty is in remembering the numbers of tools where they run into seven or eight digits, which would be necessary for a complete classification. If an attempt is made to carry the numbers on the drawings, erasures and mistakes are likely to occur. Many other schemes and combinations of classification may be worked out, but they will all have the same inherent weaknesses.

Example of a Numeric System.—A six-digit system of tool classification was found to work satisfactorily in one case. Throughout the plant in both part-designing and tool-designing the metric system was used. Thus, the tool classification as regards size was based on metric units. The principles of this six-digit system were:

Every tool of exactly the same design had the same six-digit number.
The main group was indicated by the first and second digits, of which the first indicated the main class of operation that the tool could perform as follows:

0 – Tools for miscellaneous use
1 – Circular cutting tools
2 – Flat cutting tools
3 – Impact tools
4 – Tools for making holes
5, 6 – Tools for holding and steadying
7 – Tools for threads and gears
8 – Tools for grinding and polishing
9 – Tools for measuring and checking

The subdivision was indicated by third and fourth digits, of which the fourth indicated the main size in millimeters.
The fifth and sixth digits indicated the consecutive number.
Zero as any digit except the fifth and sixth indicated unclassified or miscellaneous tools.

The fourth digit changed for every 1, 10, or 100 mm. main size, depending on class of tools, which meant, for example, that 99 numbers were available for different plain milling cutters (class 156000) within 10 mm. thickness, 99 for different grinding wheels (class 815000) within 100 mm. diameter, and so on. The correct size was given for each subdivision in classification lists.

The main feature of this classification system was that all similar tools within a certain size range of rather close limits had exactly the same four first digits; in other words, these figures told a definite story.

For example, every twist drill with taper shank over 20 mm. but under 30 mm. in diameter had a six-digit number beginning with 4212, these four figures identifying this type of tool without the need for referring to any other record:

400000 – Tools for making holes
420000 – Drills
421000 – Twist drills with taper shank
421200 – From 20 up to (but exclusive of) 30 mm. in diameter

Another important feature was that this system forced the user actually to classify the tool, not merely to add another decimal or letter as in other systems. A tool number could never be correct with more or less than six digits.

This six-digit number was used all the way through to identify the tool:

1. As drawing number for every tool that could be conveniently drawn on a standard 8½ x 11 in. sheet.
2. As number on records of any kind.
3. As identifying number stamped on each tool.

Tools of the company's own manufacture carried, in addition, an individual "serial" number, so that reference could be made at any time to the order on which any tool was made if found unsatisfactory, and a change made in the material used or the method of manufacturing. Tool cribs throughout the plant were arranged according to number. This

plan automatically placed similar tools together, thus cutting out a lot of record keeping, danger of misplacing, etc. The tool classification helped to control the total expenditure for small tools, showing a direct saving of about $50,000, or a decrease of over 20% of the total cost of tools in one year.

LETTER SYSTEMS.—Straight letter systems without special features have probably been tried in some cases for tool identification but are not often used because of the trouble involved. They are not so naturally and readily adapted to orderly and logical applications as is the case with numeric systems. For limited uses the straight letter system might give satisfactory service but the superiority of other methods makes the latter far more useful for most applications.

THE MNEMONIC SYSTEM.—The principle of a mnemonic letter system, for tool classification, which should be clearly distinguished from the straight letter system, was stated thus by Gilbreth: "All tools that are alike shall be together, and those that differ by one variable only shall be contiguous." In applying this principle tools are subdivided into general classes, the arrangement being according to the functions that they perform, taking into consideration where and how work they perform is done. Next, these groups may be divided into classes and each class further divided and subdivided, as in Fig. 1, which is the Gilbreth key sheet of the general tool group, and is similar to the Taylor Key. The mnemonic, or memory, factor is introduced by using for each class a letter significant in identifying the class. Thus A is the first letter of Abrading, B for Blanking, and F (fire) signifies heat and its associated phenomenon light. Tools are thus arranged alphabetically as well as mnemonically.

Classifying Tools by the Mnemonic Method.—To classify a tool, look first at the key sheet and find the general group in which the tool belongs, after which make up a key sheet with subdivisions for that group. To do this, take a sheet of paper and fill in general group symbols at the top, as shown in Fig. 3. Then enter classes of tools in this column, assigning the alphabet letter which corresponds to the first letter in the noun of the tool term. In cases where the name of more than one

M – Measuring Devices

All gages and instruments of precision

M	A	M	N – Indicators
	B – Bevels		P – Protractors
	C – Calipers		Q – Squares
	D – Dividers		R – Rules
	E – End measuring rods		S – Scale weighing
	F – Reference disks		T – Timing device
	G – Gages		U – Plumb bobs
	H – Pressure gages		V – Verniers
	J		W
	K – Electrical		X – Heat measuring
	L – Levels		Y – Miscellaneous
	M – Metering		Z

Fig. 3. First Stage of Classification Breakdown of Measuring Devices

tool begins with the same letter in any given subdivision, use letters that give the most distinctive sound to the word. Thus, in the subdivision in Fig. 3, letter E was used for end measuring rods. Therefore, it is necessary to assign another letter to electrical instruments, which in this case is K. Letters O and I are omitted because they are likely to be confused with figures.

As an example, suppose a 5–5½ in., external, adjustable, limit gage of the caliper type is to be classified. On the group head sheet M, Fig. 3, under G appears the class gages. A gage head sheet is made out and on this sheet, under C, place caliper gages. Next the head sheet for caliper gages MGC is made out. Adding the letter E for external gages gives MGCE. On another sheet list the different types of external caliper gages. Letter L is used for limit gages. On the head sheet MGCEL under A enter adjustable gages. This classifies the particular gage in question to its smallest variable. The complete symbol for a 5–5½ in., external, adjustable, limit gage is MGCELA 5–5½ in. The steps are indicated in the accompanying breakdown.

MG	A
	B
	C – Caliper
	D – Depth
MGC	A
	B
	C – Combined external
	D
	E – External
MGCE	A
	B – Bar type
	C – Type
	D
	L – Limit
MGCEL	A – Adjustable
	B
	C
	D – Double-end

In like manner any tool may be classified. Letter Z of each head sheet is left for special tools of that division which cannot be otherwise classified.

MARKING SYMBOLS ON TOOLS.—Every tool should be marked plainly in a conspicuous place with its tool symbol in such a manner that the marking will be permanent. Cutting tools designated by size should have tool size added to symbol. Special tools for a particular manufactured part are often stamped with that part number. If the tool is soft, or has a soft spot, the symbol should be stamped with a die. If the tool is hard or delicate, so that it might be injured by stamping, the symbol should be etched. Electrical etching apparatus will pay for itself in a short time where much tool marking is done. Size of characters should be large enough to be easily read. One-eighth to one-quarter inch high is satisfactory. Small characters cause loss of time in identifying the tool in the hands of the workman, or when replacing in

storage. Characters on cutting tools, such as drills, reamers, counterbores, and the like, should be such that they can be read in any light in an ordinary shop. Figures ordinarily stamped on by manufacturers are difficult to read at the machine. Often a tool must be carried to the light before the symbol can be understood. To accommodate large characters it is usually necessary to grind flats upon shanks of round tools. These flats serve the double purpose of permitting the use of satisfactory characters and also of indicating instantly the location of the tool size. Both features conserve time where it is necessary to verify size of tools prior to use.

Large plants engaged in mass production prefer not to stamp parts numbers on small tools because the tools may be used for a number of different parts and confusion would result. Likewise, there would be no definite number to identify the tool. A tool number the same as the tool drawing number is frequently used instead, and the tool is specified by this number on the operation sheet for each part on which it is to be used.

The Tool Crib

LOCATION.—There are three general methods in use for tool storage:

1. Large central tool crib into which all factory tools are concentrated, and from which they are issued.
2. Sub-tool-crib system. This method provides a central, or head, tool crib which acts more in the capacity of a storeroom than that of an issuing tool crib. Each department, under this system, has a sub-tool-crib which carries only tools used by that department. When these sub-tool-cribs need additional tools, they requisition them from the main tool storeroom.
3. Flexible plan whereby a movable tool crib is provided in the form of an elevator operating through several floors so that, upon signal or upon receipt of tool issue slips, it can go up or down to the floor where the department needing tools is located and make deliveries from its shelves.

Factors in the problem of where and how to store tools are (Christensen):

1. **Size and layout of factory.** Cost of tool distribution from a single, central tool crib may be excessive in large factories.
2. **Allocation of space to departments.** One section of a factory is sometimes given over to assembly and testing, while other sections are used for fabrication of parts. Relatively few tools are needed in the former, while the latter may require the use of every kind of tool that the factory owns. Obviously, the cribs should be placed nearest to the departments that use the most tools.
3. **Nature of product.** Some products lend themselves to complete fabrication, assembly, and test in a single department. Many companies have one or more articles of this kind. In cases where a department functions independently of the rest of the factory, it may be advisable to have a tool crib solely for its use.
4. **Methods of operation.** Products manufactured determine methods of operation to follow. In factories where process methods are used, such as textile mills or cement plants, tool requirements are different from those of a highly developed machine shop.

5. **Grade of workmen employed.** High-grade workmen take pride in good tools and are generally careful in their use. Machine attendants, however, are not always so careful, especially if they are on piecework. As a rule, factories that use piecework have a more complex tool problem than those that operate on day rate.

Tool requirements include determining what tools are needed for each particular operation, and the general tools which are likewise required. A study of tool requirements is important.

In general, the location of a tool crib is governed by facilitation in receiving and checking out tools. Tool delivery, however, should not conflict with general transportation activities in the factory. Neither are tool cribs always put where they would be most convenient for the issuing of tools, especially where they would then be set in the middle of some manufacturing area and thus interfere with the flow of work.

Men selected for responsible operation of a tool crib system should be chosen with regard to a knowledge of, and familiarity with, tools, appreciation of responsibilities of the work, and suitable personal characteristics. Preferably they should be men with a good understanding of machine processes. A classification for such personnel is: foremen, tool inspectors, clerk, group attendants, laborers, and possibly apprentices.

LAYOUT OF TOOL CRIB.—The layout of a tool crib depends upon the area allotted to it and the shape and relative dimensions of this area. Layouts, consequently, are sometimes expedients, but often can be definitely planned to give the greatest efficiency in tool storing, issuing, receiving back, inspecting, reconditioning, replacing on shelves, and record keeping.

Space Required for Tool Cribs.—General principles which aid in the proper location of space for each class of tools are:

1. The tools should not, as a general rule, be stored over 6 ft. high. The top sections of bins should be left empty in the beginning to take care of additional tools of each class which are sure to accumulate as time goes on.
2. Tool sizes are given in dimension, number, weight, etc. For example, twist drills are made in size increments of 1/64 in. Therefore, a rack for drills should have a space for each 1/64 in. from smallest to largest size carried, provided 64-in. sizes are used throughout the entire range.
3. Aisle space between bins should be ample for free passage of men through them. Thirty inches for bin aisles, and 36 in. for main aisles have been found suitable, but should be a minimum.

It is evident that the space required varies with the number of tools to be handled, as well as the variety of each class of tool. Expenditures for establishing an operating tool crib are classed as overhead, and for this reason should be kept under control. Space assigned should be limited to that which is necessary. At the same time it should be ample to avoid the tendency to overcrowd the crib and thus hamper its effectiveness.

TOOL STORAGE EQUIPMENT.—There are three principal requirements to be satisfied in determining upon tool storage equipment:

1. Adaptability. Storage should be especially suited to the nature of tools it is to contain and should occupy a minimum of space.
2. Flexibility. Storage space must be capable of indefinite expansion along consistent lines.
3. Uniformity. Storage space should be of uniform character to permit of expansion with a minimum of standard unit storage bins, boxes, or racks.

Steel versus Wood Shelving.—Steel storage shelving and bins are widely used for tool storage because they come in standard sections, with special provisions for tools, can be assembled, taken down, and reassembled in any way with 100% salvage of sections, and drilled for dividers at 1-in. intervals vertically and 2-in. intervals horizontally.

Wood bins are used occasionally for tool storage, although not nearly so frequently as formerly, because of fire risk, splinter danger, uncleanliness and unsightliness, high waste of space by thickness of members, vermin harboring, difficulty of changing, low salvage value, etc. Essentially the advantages and disadvantages that apply to wood bins for storing materials apply also in the storage of tools. The main advantage of wood is protection of delicate tool edges or surfaces, but steel bins can be plywood- or plastic-covered where such a preventive is necessary.

Tool Crib Operation

METHODS OF PROVIDING TOOLS.—The three ways by which tools are made available to the men needing them are:

1. Allowing workmen to keep in their possession all tools necessary for their use.
2. Having workmen go to tool crib for tools. This plan wastes time, encourages idleness and conversation, shuts down machines, and holds back production. It is not recommended where other methods are feasible.
3. Sending tools to workmen upon requisitions forwarded to the tool crib in advance.

The conditions under which these different methods are used vary according to the kinds of work carried on in the different departments:

1. Departments that regularly fabricate parts for orders or for stock. The workmen in these departments should have every tool delivered in advance of starting the job, from predetermined tool lists and tool requisitions supplied by the production control department.
2. Assembly, erection, and test departments. In these departments, each man should be given a kit of tools sufficient for his general use. Any special tools needed should be drawn from his crib as occasion requires.
3. Departments on special-order or job-shop work. Where orders can be preplanned, the tools should be delivered in advance, upon regular tool requisitions.
4. Departments doing irregular, short-run jobs, and toolrooms and maintenance departments. The situation in these shops is too varied, erratic, and complicated to make the use of predetermined tool lists practicable. Distribution of tools in these departments may be done by messengers, either from the respective departments or from the tool crib. In some cases it may be necessary for the workman or

toolmaker to go personally to the crib for tools. Toolmakers are well qualified to determine what tools are needed for the work at hand.

Delivery to User.—Where tools are delivered, and not secured by the workers themselves or furnished to them in kits, the following methods are in use:

1. The dispatcher or foreman in a department sends tool requisitions or lists—preferably prewritten in the production control department—to the tool crib in advance of starting jobs and has them delivered.
2. The central planning department sends the tool requisitions, with dates of delivery indicated, to a central tool crib where they are sorted by dates, and deliveries are made accordingly.

Deliveries are made by:

1. The requisitioning department trucker, who brings the requisitions or calls at the proper time after they have been sent by messenger or plant mail service.
2. Tool crib truckers or messengers.
3. Plant transportation system truckers or messengers.
4. Pneumatic tube systems or plant mail service, in the case of smaller tools. The pneumatic system is highly economical in large plants and for speed and the safe transportation of valuable tools.

FACTORS IN GOOD SERVICE.—Tools should be kept in locked tool cribs, from which all but tool clerks should be excluded, and should be issued only upon duly authorized requisitions. The following is a general set of conditions which should be satisfied:

1. Careful, accurate, and rapid service should be maintained at all times. The tool crib attendant should have tact, and ability to interpret quickly any poorly described requirements of the workman and hand him a perfectly conditioned tool with the least possible delay.
2. Location of tools, as well as the party who is responsible for them when they are not in the crib, should be known at all times.
3. Every effort should be made to insure that the workmen really get the tools they need. Conversely, tools should not be issued to men who have no use for them.
4. Any breakage should be promptly checked up and charged to the proper account. Undue breakage should be abated without delay.
5. Tools that are charged to the workmen should be checked up frequently.
6. Unnecessary or unused tools should not be allowed to accumulate in the workmen's possession.
7. Tool crib attendants, to carry out the above rules, should be chosen carefully. They should have a well-developed appreciation of responsibility, and be familiar with tools and their trade names. They should be courteous, accurate, and attentive to duty. Anyone who has these qualifications may learn to disburse tools in a short time.
8. Necessary records should be as simple as possible.
9. Records should be so devised that workmen have as little writing to do as possible.
10. The more complicated operation of record-keeping should be done by a clerk competent to handle that kind of work.

CHARGING OUT TOOL ISSUES.—It is important to charge out and keep records of the issues of tools because of the following factors:

1. Value of tools, which makes it imperative to prevent their loss and secure their return.
2. Need for their use on other jobs to keep production going, thus necessitating prompt replacement in the tool crib, or location in the shop if they have to be recovered for immediate transfer.
3. Keeping tools continually in good shape, by getting them back for prompt inspection and repair.
4. Replacing tools that are lost, broken, or damaged, by placing purchase or manufacturing requisitions at once, especially when replacement requires a long time.
5. Fixing responsibility for the possession and good care of the tools to prevent carelessness on the part of workmen.
6. Maintaining a history of use to guide in future purchasing—as to vendor—and in determining tool life, replacement time cycles, and quantities to carry on hand.

There are a number of methods under which tools are charged out, each having features making it of particular use under certain circumstances. These methods are:

1. Single-check system.
2. Double-check system.
3. Triplicate tool-slip systems.
4. Electric machine method.
5. Metal plate method.

Single-Check System.—Under the single-check system the worker securing a tool from the tool crib, either in person or by delivery service, gives for it a brass check with his number stamped on it. This check is hung on a hook by the place where the tool is kept, or it can be hung on a board indexing the tools. If the tool is wanted, the toolkeeper knows who took it, but not when or for what job, or whether the check is on the right or wrong hook, or if some other worker used a fellow-worker's check, and there is no record of how many tools the worker may have withdrawn. This plan is used in only the simplest cases.

Double-Check System.—The double-check system is similar to the single-check system and has the same characteristics and faults. Its only other feature is that the second check is hung on a hook under the worker's number and thus it can be seen how many (but not which) tools he has secured.

Triplicate Tool System: Spring-Clip Boards.—One variety of the triplicate tool-slip system (McCaskey) makes use of spring-clip holders as record compartments, the tool slips being filed back of the clips, in a manner similar to that in which stores requisition slips are sometimes handled. When an employee calls or sends for a tool, he fills out a tool order (Fig. 4) in triplicate with one writing, using inexpensive carbon-backed forms—original white, duplicate yellow, triplicate pink. The workman writes in his clock number, date, tool drawn, and signs his name. The tool number is entered on the order by the crib attendant, and the tool is handed to the workman with the yellow copy which he keeps in a slip-holder on his machine or bench. The white copy acknowledges receipt of the tool and is retained and filed in the workman's compartment back of the clip bearing the man's number, and the pink copy in the tool compartment back of the clip for the particular tool. The cabinets containing these records may be closed and locked. During a rush, the

TOOL ORDER No. 6561

Dept.______ Bin No. 560

Clock No. 63 Date 2/10

QUAN	SIZE	KIND OF TOOL
1	1"	Exp. Reamer

WORKMAN NOTE THIS TOOL IS IN YOUR CHARGE UNTIL IT IS RETURNED IF LOST IT WILL BE CHARGED TO YOU KEEP THIS SLIP UNTIL TOOL IS RETURNED THEN EXCHANGE IT FOR YOUR WHITE SLIP.

Signed J. Jones

This Tool Order is for one item only.

FIG. 4. Typical Tool Order Made Out in Triplicate

attendant hands out tools and yellow slips rapidly, but delays filing white and pink slips until the peak is over. This plan speeds up service and permits men to return to work.

The tool crib attendant, under this method, can tell instantly what tools have been issued to each workman, and the exact location of every tool out. When the employee returns a tool he also returns his yellow copy of the tool order. If the tool is in good condition, the tool crib attendant removes the corresponding white slip, matching the serial number which appears on all three copies of each set, and the workman immediately destroys it. His responsibility for that particular tool is ended. Then, or later, the attendant removes the pink copy from the tool record compartment, thus indicating that the tool has been returned, but not destroying the record of the transaction. Pink copies, and in some cases the yellow copies, are filed to provide data for purposes described below. The tools need not be replaced in the bins at once, but may be held for further inspection or repair. Thus the accumulation of defective tools in the bins, which may occur under the brass check system, is avoided.

A broken or defective tool is accepted by the tool crib attendant only when accompanied by explanatory report, O.K.'d by the foreman of the employee returning it. The report may be made on the employee's yellow copy of the tool order or on a separate form. If carelessness or inefficiency of the workman was responsible for breakage, the report may be filed at the back of his compartment. Such breakage may be reduced either by warning the small percentage of offending employees against continued carelessness, instructing them in tool use, or transferring them to other work. Occasionally the reports provide the basis for raising the working efficiency of entire departments.

When a defective tool is returned for repair, the report may serve as a repair order, indicating the department to which costs are to be charged. When a tool has to be junked, the report may provide the accounting department with the basis for charging it against the department responsible and crediting it to the tool investment account. If it must be replaced by a new tool, an explanatory report may be attached to the requisition, justifying the issuance of the new tool from stock.

If tools are found to be inferior, defective or unsuited to the work, reports may be filed in the tool compartments back of the pink slips. Evidence thus accumulated may indicate to the production and purchasing departments that certain brands or types of tools last longer than others, or function better under specific conditions.

A tabbed tool inventory card, placed at the back of each tool compartment, with the entire top visible, shows the name and description of the tool, its location, maximum and minimum quantities, or reordering points, purchase price or appraised or depreciated value, and provides columns for receipts, scrapping, and remaining balances, with dates. The quantity of each tool on hand is the number in the bin at any time plus the number in use as shown by the pink slips. Control of inventory is thus readily carried on.

Tool activity, or the frequency with which tools are issued, is indicated by accumulating pink copies of tool orders behind the inventory cards when tools are returned. Once a month the slips for each kind of tool are counted, the number is recorded on the back of the inventory card, and the slips are then destroyed. An analysis of pink or yellow slips after tools are returned will show the departments which used the tools, the investment involved, length of time they were out, proportion of breakage, and other essential factors for closely accurate allocation of tool costs to the various departments.

When tools are issued together as a kit, the transaction can be handled on one tool order. The combination is given the equivalent of a tool number, such as Kit or Set-Up No. 25. The individual tools in the kit are charged against that number by the attendant to maintain the accuracy of the tool records. The workman is given a standard list of tools in the set-up for which he is responsible. When a workman requisitions tools from several cribs, his use of tools may be controlled through some one crib to which he is assigned, or through all of them. The former plan is advantageous if the employee leaves and is checked out, since the records of all tool withdrawals are in one place.

Card Record System, in Triplicate.—Supplanting a brass check plan, the Osborn Manufacturing Co. installed a Kolect-A-Matic tool control system consisting of pockets with celluloid tips mounted on panels which rest vertically in a tray. Records of a permanent nature are placed under the celluloid tip, but temporary records, such as tool loan orders, are merely dropped in the pockets.

Three separate records are kept: the employee's name, filed by employee number, on which tool loss and breakage are recorded (Fig. 5a); the tool inventory control, on which ordering, receiving, and balance-on-hand information is kept (Fig. 5b); and the part name, on which standard and special tools needed to make the part are listed (Fig. 5c). The tool inventory control should always show a balance equal to the

539
EMPLOYEE NO

Smith John
EMPLOYEE NAME

DATE	NAME OF TOOL	EXPLANATION OF LOSS OR BREAKAGE	DATE	NAME OF TOOL	EXPLANATION OF LOSS OR BREAKAGE
1/30	17/32 Drill	Carelessness			
2/15	1/2"-13 Tap	Too Fast Feed			
2/[illegible]	3/4-10 Tap	Hard Casting			

OSBORN MFG CO

REMINGTON RAND INC

Fig. 5a. Employee's Record Card of Tools

17/32 Drill

LOCATION	SECTION	SHELF	BIN
	5	A	1

MKP-429

TOOL SPEC: HIGH SPEED

MINIMUM | ORDERED | OVERSTOCK | UNIT

TOOL INVENTORY CONTROL

DATE	EMPLOYEES NUMBER	DEDUCT	BALANCE	DATE	EMPLOYEES NUMBER	DEDUCT	BALANCE
	9-1	Inv.	10				
1/28	P126105	+24	34				
1/30	539	-1	33				
2/1	650	-1	32				

ORDERED				RECEIVED		
DATE	ORDER NO	VEN	QUANTITY	DATE	QUANTITY	UNIT COST
1/26	P126105	1	24	1/28	24	1.10

BI-MONTHLY SUMMARY MON	19	19	19
JAN FEB			
MAR APR			
MAY JUNE			
JULY AUG			
SEPT OCT			
NOV DEC			
TOTAL			

NO	VENDOR
1	CLEVE. TWIST DRILL
2	
3	
4	
5	
6	

DATE 12/30 MAX. 40 MIN. 12

U S PAT NO

FIG. 5b. Tool Inventory Control Card

PART NO	PART NAME	SECTION	BIN	SHELF
D-3931-A	Valve Cover		6	B

USED ON MACHINES		ALSO USED ON PART NO		TYPE OF JIG FIXTURE OR TOOL SET	
	714 PJ Jolt Control Valve		C-5119-A		Drill Jig

LIST OF STANDARD TOOLS

SIZE	DESCRIPTION
17/34	Drill
3/4	"

LIST OF SPECIAL TOOLS OR TOOL SET

TOOL NO	DESCRIPTION
TD-3931-A	1 7/32 Core Drill
" -B	1 19/32 " "
" -C	1¼ Piloted Reamer
" -D	1 5/8 " "
" -E	1 15/32 Core Drill

DESCRIPTION OF OPERATION

17/64 Drill one hole

3/4 " 1 7/32 Drill & 1¼ Ream 2 Holes

1 15/32 " 1 19/32 Drill & 1 5/8 " 1 Hole

BORN MFG CO

FIG. 5c. Parts Card Listing Tools Required for Making the Part

quantity of tools loaned as recorded on slips, plus the number still in the crib.

In operation, the employee fills out a tool loan order (Fig. 6) in duplicate. The original is filed with his employee name card, the duplicate

ORIGINAL

TOOL LOAN ORDER

QUANTITY	SIZE	DESCRIPTION OF TOOL
1	1/2	HAND REAMER

CLOCK NO	DATE	SIGNATURE
539	1/26	John Smith

44412

Fig. 6. Tool Loan Order for Issue of Tool to Worker

with the tool inventory control. Upon return of the tool he receives the original. The duplicate is pulled for later recording on a tool usage report.

The employee is responsible for all tools for which signed originals are found in his record pocket. If he should break a tool he shows it to his

ORIGINAL

Broken or Damaged Tool Report

SIZE	DESCRIPTION OF TOOL
3/4-10	TAP

REASON

HARD CASTING

CLOCK NO.	DATE	WORKMAN'S SIGNATURE	DISPOSITION
539	2/20	John Smith	SCRAP ☑
FOREMAN'S SIGNATURE			REPAIR ☐
H. Haquish			

00165

No New Tool Furnished Without This Report in Full

Fig. 7. Broken or Damaged Tool Report

foreman and receives a broken or damaged tool report (Fig. 7) made out in duplicate. Both copies are turned in with the tool, posted to the employee's name card and deducted from the tool inventory control. At the end of the month a broken-tool distribution report by departments and shifts is prepared for the management. Thus any inefficient departments and careless employees will be shown up by the records.

The part name record is kept in the tool crib as a listing of the standard and special tools, jigs, and fixtures required for making certain parts. When a part is to be made the planning department merely notifies the tool crib and all necessary tools are gathered so that production can proceed without delay.

Electric Machine Method.—Under the recording machine plan, when a tool is issued the tool number or symbol, employee number, and date are set up by keys, after which a bar is pressed and the information is printed on a consecutive tape together with two tickets, thus giving legible records. The original ticket is signed by the workman withdrawing the tool, and this ticket is filed under his number in the employees' tool record file. The duplicate is placed in the ticket holder at the bin from which the tool is withdrawn, or it can be posted on a tool issue board or in a file.

When the worker returns the tool, he receives back his signed slip. The duplicate slip is used for analysis as in other systems, or, if the tool is damaged, goes into the broken or damaged tool file until the disposition of the tool is determined (The Controller, vol. 11).

Metal Plate Method.—To save repeated filling out of standard information on tool issue slips, one variety of the metal plate system prints the employee's name, number, department number, date-entry line, and facsimile signature on plates for each worker, and an index is set up by cards printed from the plates. Plates for each tool carried are also made, from which bin labels and cards for a tool index system are printed. When tools are to be issued, the corresponding plates for employee and tool are taken out and run off on two-section tool slips, each section showing the full information from these plates. The employee section of the card has with it a perforated section for the employee to sign, acknowledging receipt of the tool. The employee portion of the card is filed in the employee index file behind his name or number, and the tool portion in the tool index behind the tool number, symbol or name. Upon return of the tool the employee is given his receipt stub, the remainder of the card serving as a memorandum to remove the corresponding card from the tool index file, thus clearing the record. The used cards may be summarized to indicate tool activity as in other systems.

Another plan used provides plates for parts to be manufactured, giving data identifying the part, data on material for it, routing, and number of operations. These plates are used to print data on manufacturing orders, material requisitions, identification tags, labor tickets, tool notices, etc. The tool notices for the respective operations on a part are filed in job envelopes and go with the envelopes, through scheduling and production control, to the successive operating departments, in each of which the work dispatcher (or foreman) removes the tool notice—if tools are needed—for the operations to be performed there and sends

them to the tool crib with the work order card on which the tools required are listed and detailed. The tools are then charged out and supplied and, after the operation is done, are returned to the crib with the filled-out finished work order for identification. The tools are replaced in storage, the charges and notices are canceled, and the work order is forwarded to the production control department for recording (The Controller, vol. 11).

A COMPANY-WIDE SYSTEM FOR ISSUING TOOLS.—In the various divisions of the Westinghouse Electric & Mfg. Co. the tool control system in use is divided into three parts: permanent tool issues, temporary tool issues, and set-up tool issues (Sipe, Fact. Mgt. & Maint., vol. 102).

Permanent Tool Issues.—Permanent tools are those retained by an employee as long as he stays on the job where these tools are needed. Tools are issued upon requisition (Fig. 8, two copies), made out by the foreman, the original going later to the personnel department as a "record of permanent issue," the duplicate being given to the employee. The tool crib attendant fills out a "record of tools supplied" card (Fig. 9) listing the tools, which is signed by the employee and kept in the tool crib. If the employee is transferred to a department serviced by another tool crib, or leaves, he turns back his tools, they are checked off the record card, costs for any missing tools are entered on the card (together with shortages on any temporary tool list), the card is approved by the foreman and goes to the personnel department for check against the "record of permanent issue" slips.

Temporary Tool Issues.—Temporary tools are those to be returned after a job is done. Such tools are issued separately upon a signed tool "request" (Fig. 10) or "order" (Fig. 11) made out by the worker, the number of parts in the

TOOL REQUISITION

Tool Room X-24

Name of Workman	Section	Dept.	Check No.	Tool Sheet No.	Tool Checks Yes ☑ No ☐	Lock Yes ☑ No ☐
J. B. Doe	X	24	114	1	No. 114	No. L 142

☑ New Tools ☐ Exchange	If "Exchange" State Why	Order No.	Charge Account

Quantity	Description	Item No.	Price per	Value
1	Mallet - Rawhide			
1	"S" Wrench			
1	1" Chip Brush			
1	Flat Clamp			
1	Drill Press Chuck			
1	Cold Chisel			
1	6" Three Cornered File			

Date 7-6 19— Approved John Smith FOREMAN

Fig. 8. Tool Requisition for Permanent Issues

NAME J. B. Doe TOOL CHECK NO 114

SEC.	DEPT.	CHECK	SEC.	DEPT.	CHECK	SEC.	DEPT.	CHECK	LOCK NUMBERS		LOCKER NO
X	24	114							L142		

AMT.	DESCRIPTION OF TOOL	AMT	DESCRIPTION OF TOOL
1	Mallet Rawhide		
1	"V" Wrench	.60	
1	1" Chip Brush		
1	Flat Clamp	1.00	
1	Drill Press Chuck		
1.	Cold Chisel		
1	6" Three Cornered File		

RECORD OF TOOLS SUPPLIED (SEE OTHER SIDE)

FIG. 9. Record of Tools Supplied

tool—if more than one—being noted. The issue date is stamped on the request and the slip is placed on the checkboard or in the file against the employee's number. If a "request" form is used, a check of the employee is taken from the checkboard and is hung at the bin from which

TOOL REQUEST No 277083

TOOL QUANTITY 1 DESCRIPTION 3/8" T. S. Drill, H. S.

I ASSUME RESPONSIBILITY FOR THIS TOOL AND AGREE NOT TO MISUSE OR REMOVE IT FROM THE COMPANY PREMISES

SECTION X-24 CHECK 114

No 277083 NAME J. B. Doe

TOOL LOANED 7-8-

TOOL RETURNED 7-8-

REPAIRED REPLACED AS NOTED ON FORM 3573

TOOL ORDER WESTINGHOUSE FORM 22036A No 1164

535 591 592 ✓ SECTION X-24 CHECK # 114

TOOL # — TOTAL VALUE $ 1 ¢ 55

LOCATION R. 1- B12

TOOL QUANTITY 1 DESCRIPTION 3/8" T. S. Drill, H. S.

I ASSUME RESPONSIBILITY FOR THIS TOOL

SIGNED J. B. Doe

TOOL LOANED 7-8- TOOL RETURNED 7-10-

AS NOTED ON FORM 3573 ☐ REPAIRED ☐ REPLACED

FIG. 10. Tool Request for Temporary or Set-Up Jobs

FIG. 11. Tool Order, Used Like a Tool Request

the tool is taken. If an "order" is used, a duplicate is made which goes in a pocket or clip at the tool bin. When a tool is returned—if it is in proper condition—the charge slip is removed from the employee's file, stamped with the date, the tool is inspected, and the perforated signed stub is detached from the "request" and given to the employee or the signed tool "order" is returned to him. The remaining portion of the

TOOL ASSIGNMENT

No. 3904

SET UP TOOLS FOR DRAWING NO	ITEM	DATE
A-247293	4	7-6-

MACHINE	MACHINE NO	SECTION	GROUP	CHECK NO
Drill Press	123	X-24	9	114

QUAN	DESCRIPTION	TOOL NO
1	Drill Chuck	D212
1	Drill Socket	D342
1	Drill Sleeve	D138
1	3/8" T.S. drill H.S.	--
2	U. Clamps	U-45
1	Drill Vise	V-71
1	"S" Wrench	-
1	1" Chip Hammer	-
1	T.S. Expansion Reamer	-

WORKMAN'S SIGNATURE	SUPERVISOR'S APPROVAL
J. B. Doe	John Smith

NOTE: THE EMPLOYE ON EACH SHIFT USING THE ABOVE TOOLS MUST MAKE OUT TOOL REQUEST FORM 81793 OR 22056 AND HAVE SAME TRANSFERRED TO HIS ACCOUNT, RELEASING PREVIOUS SHIFT EMPLOYE

FIG. 12. Tool Assignment for Group Issues on Set-Ups

"request" is put in a tool request container. As tools are replaced in bins, the employee's check (if a "request" was used) or the duplicate copy of the "order" is taken from the bin, the former being replaced on the checkboard or the latter put in the tool request container.

From the slips in the tool request container a daily tool activity report and a report on tool breakage or damage in the section are made. A worker returning a damaged tool fills out a tool requisition (Fig. 8), has it approved by his foreman, and the tool crib attendant staples it to the tool request or order put in the container so that proper charges may be made against the section. Lost tools are recorded on a tool requisition, on which the cost is entered, this form is approved by the foreman, and then goes to the personnel department for the "record of permanent issues."

Set-Up Tool Issues.—When more than one tool is needed on a set-up used on two or more successive shifts, and these tools will then be returned to the tool crib, the set-up tool plan is followed.

A tool assignment (Fig. 12), made out in duplicate and signed by the employee, lists all the required tools. A supporting set of tool requests (or tool orders) is also made out and signed on which the serial number of the tool assignment slip is recorded. The employee keeps the original tool assignment, and hands the duplicate and the tool requests (or tool orders) to the tool crib attendant, who issues the tools, stamps the date

on the supporting tool request (or tool orders), staples the duplicate assignment and the request (or the two copies of the tool orders) to the duplicate assignment, and files these papers under a spring clip near the checkboard or issuing window.

When the shift changes, the worker succeeding to the job receives from the original worker the original tool assignment slip, checks it against the set-up, and gives a set of supporting tool requests (or orders) to the tool crib attendant. The latter then forwards to the original worker the signed portion of his tool requests or the originals of the tool orders. The process is repeated with each successive shift.

After the job is finished and the tools are returned, the tool crib attendant removes from the tool assignment the stapled tool requests or orders, stamps on them the date of return, inspects the tools and if they are in good condition detaches the final signed request stubs or original orders and returns them to the last employee on the job, puts the requests or duplicates of the orders with the tool assignment in the tool request container, and returns the tools to their respective bins.

If any tools are damaged a tool requisition, signed by his foreman, is filled out for them by the worker, turned in at the tool crib, and, with the tool request or order attached, is filed in the tool request container for recording and for charging to the section. Lost tools, likewise, are recorded on a tool requisition on which the cost is entered, the requisition is approved by the foreman, and is then sent to the personnel department for the "record of permanent issues."

Tool Inspection and Repair

TOOL INSPECTION SYSTEM.—Systematic inspection and supervision of tools is a necessity. Frequent and systematic checks should be made to insure that:

1. The tool crib is kept neat and in order. Good housekeeping is conducive to better care of tools and more efficient tool crib service.
2. Workmen are served with tools promptly. Charging out issues should be done only after orders for tools are filled.
3. Supply is kept up to fixed quantities.
4. Tools are always in good working condition.
5. Old and obsolete tools are promptly scrapped.
6. All rules and regulations pertaining to the tool system are carried out.
7. The tool system is cooperating with the other departments in the factory. The tool crib is a service department whose principal duty it is to facilitate manufacture.

Standing Orders for Inspection.—To insure that every tool is inspected every time it returns to the crib from the shop, specific instructions are advisable. These standard practice instructions can be worked out on the basis of standing orders so devised that all points to be inspected are covered in natural sequence in the operation of picking up a tool and returning it to its bin. As an illustration, it is most convenient to take up a twist drill by its shank, look first for the condition of the cutting edge, then of the radial clearance and lastly of the shank itself, especially the tang, at the time the drill is being placed in its rack.

This form of inspection is done while the tool is being handled. If the tool seems to require repair, it is placed on a tool inspector's bench later to be examined and tagged for repairs if necessary. The type of inspection to be given varies with the kind of tool and class of shop. Existing conditions determine what standards for inspection to establish.

Limits of permissible wear in any type of tool should be carefully predetermined and inspection should always determine whether the wear of the tool has exceeded these limits. Thus, in lathe tools, if the tool has been ground so that its point is less than a certain distance above the top of the shank, it can no longer be used to the best advantage. A height gage for each size of tool should be provided to determine whether the tool can stand further regrinding or should be reforged. Precision measuring instruments should always be checked against known standards. Snap gages may be sprung by careless use or may wear so that they no longer truthfully indicate size. They should be checked against inspection gages, either at regular intervals or preferably each time they are used, and if found to be incorrect, should be closed up and lapped to size. Similarly, arbors, mandrels, etc., which have worn below the limit of size allowed, should be ground down to the next smaller size. Clamping and holding down bolts should be examined every time they are used to make sure that the threads have not become damaged or that corners have not been twisted off the nuts. The standard condition of the thread on a holding down bolt should be such that a nut can be run down to the end of the thread by means of the fingers without the use of a wrench.

SHARPENING AND REPAIRING TOOLS.—Modern machine-shop practice requires that all tools be sharpened in the toolroom rather than to have the workers themselves, or even the tool crib attendants, perform this work. The cutting efficiency of a tool depends almost entirely on the tool angles, and a slight variation in these angles will reduce cutting efficiency to a marked degree. Correct angles can be secured only by grinding them in a machine set for the purpose, or by using a full equipment of angle gages if grinding must be done by hand. Another reason for grinding in the toolroom is that it is more economical to provide a workman with duplicate sets of tools, one of which may be ground while he is using the other, than to permit him to take time from productive work for the purpose of doing his own grinding.

TOOL REPAIR CONTROL SYSTEMS.—When a tool, die, jig, fixture, or other similar device needs regrinding or repair while any production order is being processed in the Republic Steel Corp., a green cardboard tag is prepared by the set-up man, inspector, or foreman, together with four carbon-backed copies: (1) toolroom dispatch order—white, (2) toolroom index—blue, (3) tool hold-up, and (4) tool promise. Copy (5) is the green tag. (T. M. Landy, Fact. Mgt. & Maint., vol. 100). Copies (1), (2), and (4) are sent to the toolroom dispatcher, and the tag (5) is fastened to the tool which is then sent to the toolroom or an outside tool shop. On copies (1), (2), and (4) a promise date is entered. The dispatch order copy is put on the toolroom dispatch board, the index copy in the tool promise file, by promised date, and the tool promise copy is sent to the production control office to be filed with the production order. The tool hold-up copy (3) goes to the production dis-

patcher in the department where the corresponding production operation is held up. This dispatcher attaches the copy to the production order, indexes the order, "Held up for tools," and puts the papers in the pocket thus labeled on the dispatch board. This dispatcher then is notified when the tool is ready and the production order can be released, by sending him the dispatch order copy. He releases the order, destroys the tool hold-up copy, sends the dispatch order copy to production control where the tool promise copy is removed from the file and destroyed. The index copy, held in the toolroom, is a record of completing the work. The tag goes with the tool to the tool crib or the user department and is there destroyed.

If tools for which no production order is on hand need repair, the usual forms are made out, the tag is placed on the tool, the dispatch and index copies are filed in the toolroom with the tool crib record to await the receipt of a production order, the tool promise is sent to production control for filing in the data file with the masters of forms, and the tool hold-up order is destroyed. When an order comes in from a customer, the production control department thus has a repair notification so that it can consult with the toolroom about the time required to repair the tool, before it makes a delivery promise. The order is kept in the pending or dead load file until the toolroom forwards the dispatch order copy to the production control department, showing that repairs have been made. Then the tool promise copy is destroyed and the order is released for production.

This plan establishes close coordination between the production control department and the toolroom. Also it provides for making tool repairs before tools are needed for jobs and thus allows for leveling the load on the toolroom.

Repairing Kits of Tools.—The Grand Rapids Stamping Division of the Fisher Body Corp. has a plan for recalling all tool kits to a central department on regular schedules, replacing any tools that are dull or damaged, and storing the kits until needed again by the shop (Fact. Mgt. & Maint., vol. 102). For each operation in the plant the tools required have been put into a special compartmented box, and the cycle of replacement of the kit has been determined, based on the time when the quickest-dulled tool in the set should be returned to the toolroom for sharpening. This use time was based on experience and was checked in practice to set cycles that would regularly supply the workers with sharp tools as soon as the ones in use become dulled.

The tool kits are delivered to the shops and returned to the central toolroom by means of electric trucks, traveling regular routes and collecting the kits on the established schedules. Upon their return to the receiving window (see Fig. 13) the kits are checked in at the scheduling desk and are put on a mechanical and roller conveyor line carrying them past an inspector who examines each tool, removes any that are broken, damaged, or worn, and puts replacement slips carrying tool code numbers in the compartments thus emptied. Repairs to dull or damaged tools are made in this section, and the repaired tools are stored in another part of the toolroom.

The kit boxes go on another conveyor unit, at right angles, into the storage section where a materials handler fills the empty compartments

with the replacement tools indicated by the slips. The boxes then go over another mechanical and roller conveyor line parallel to the incoming line. Here, after being checked, they are stored on racks until they are needed again in the shop. The outgoing deliveries are scheduled from the desk at the disbursing bench. Trips to deliver kits to workers begin an hour before the tools are due at the workplaces according to replacement schedules.

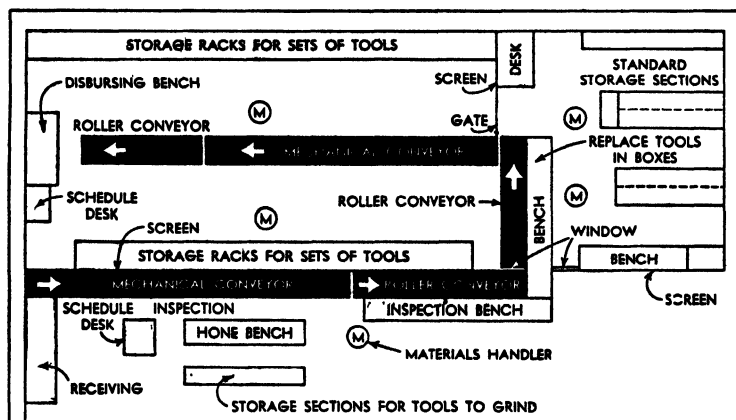



Fig. 13. Layout for Central Toolroom for Scheduled Delivery, Return, Repair and Storage of Tool Kits Undergoing Periodic Inspection and Renewal

Tool Inventories

CONTROL OF INVENTORY.—The control of the tool inventory involves records which govern procurement, quantities carried, and disbursements to tool cribs from any central tool crib or from the storeroom.

The Cleveland Graphite Bronze Co. uses the Kardex record illustrated in Fig. 14 to control the procurement and distribution of tools for ten separate tool cribs. The cut-down requisition form is 8 x 5 in. in size. When tools are to be reordered it is filled in and sent to the purchasing department. Upon placement of the order it is returned, the order number is noted in the ordered section of the lower card, the ¼-in. signal is set to show the month of order, and the requisition form is filed under the upper card. Carrying permanent information, such as vendors' names, it thus saves considerable time in reordering.

The lower card acts as the receiving and disbursement record for the entire stock and shows the balance in both quantity and dollar amount. Distribution among the various cribs is shown on the upper card. On both cards the only entries recorded as disbursements are those origi-

SP 20910 C
DESCRIPTION
CRIB
SEC
BIN
DATE
REC'D
DISB.
BAL.
SP 21217 C
PRP CODE NO.
PART NO.
ARTICLE
B/P
TIME REQUIRED TO OBTAIN
REMARKS — PRIORITY
VENDORS
1
2
3
4
5
6
DATE
QUAN WANTED
ORDERED BY
FOR STOCK ROOM
WHEN WANTED
ACCT.
PURCHASE ORDER NO
VENDOR
SHOP ORDER
DEL. TO PLANT
SUP. REQ. BY
DESCRIPTION & SPECIFICATIONS
REQUISITION FORM
CLEVELAND GRAPHITE BRONZE CO.

FIG. 14. Combined Purchasing and Distribution-to-Crib Records for Tools

TOOL NO. OR SIZE T-24796

DESCRIPTION

DWG. NO. & SIZE A-1157

SHIP VIA

F.O.B.

VENDOR

A

B

C

D

E

1. ALTER
2 REPLACEMENT
3. ENG CHANGE
4. METHOD CHANGE
5. NEW TOOL
6 ADD TOOLS
7. TOOL TROUBLE
8. REPAIR
9
10

CODE	ORDERED		DEL SCHEDULE		DELIVER TO	ACCOUNT NO	ORDERED BY	APPROVED BY	APPROVED BY	VER	P O DATE	P O NO	ITEM NO	PRICE	UNIT	BUYER	DATE COMP
	DATE	QUANTITY	QUANTITY	DATE													

802-P37

Fig. 15. Record to Control Purchasing of Tools Used on a Variety of Models and Distributed to Tool Cribs

nating from scrap reports showing that tools are no longer usable. Therefore, the balance on the lower card should always equal the balances of all cribs shown on the upper card. By centralizing the records of all cribs it is possible to effect economies by filling stock shortages in one crib from surpluses in another.

In the Bendix Aviation Corp. central control of tools is maintained by the Kardex records shown in Fig. 15, which constitute a master tool file. On the inside of the foldover card, distribution of tools to various cribs is recorded by date, department, and quantity, with the balance in stock noted. If a tool is returned or goes out of service, a check mark is put opposite its issue entry. When the minimum stock is reached an order is placed for replenishment and is entered on the upper card, which is routed for approval and sending to the purchasing department. The nature of the transaction is indicated by the code numbers keyed at the top under the list of vendors. After the purchase order is issued the remainder of the line is filled in and the card is returned to the files. Ordering quantities are entered on the front of the foldover card and receipts and balances on order are recorded.

When the purchase card is sent to the purchasing department a green punched signal is placed over the date on the visible index margin, to check on the placing of the order. Later, an orange signal is placed over the date when the first delivery is due, for follow-up purposes.

When tools are designed for new models, cards are put in a separate file, grouped by model number, part number, operation number, and tool number, and, after all tools for each model are in the cards, are transferred to the regular file. Follow-up is thus facilitated. Weekly expediting schedules are prepared to cover all tools due to be received the following month. The lists cover vendors and due dates, and are sent to the follow-up section to go to the purchasing department, outside expediters and vendors as the production schedule for the following month. Rush jobs are added as they come along.

QUANTITY OF EACH TOOL TO CARRY.—Figures showing the number of individual tools in each group to be kept in the tool crib should be worked out from actual experience as to how many of each are generally used. Standard tool lists give valuable aid in this work. After these figures are determined, a study should be made of the most economical ordering units either by purchase or from manufacture within the factory: for example, on ⅝-in. machine taps, the best manufacturing quantity is about 100 and the most economical purchase unit is one gross or above. However, this quantity is too great to keep in the tool crib, because if the crib is allowed too many tools of any specific item, the tendency is to give out new tools instead of using the old ones until they are worn out. Therefore, any excess of tools should be kept in a separate central tool crib, or in the regular storeroom and disbursed to the tool crib as needed to keep its stock to the specified quantity.

CHECKING THE INVENTORY.—A complete inventory of every tool and appliance entrusted to the toolroom should be maintained. This inventory should be perpetual in character, additions to the toolroom stock being promptly entered on it, and lost, broken, or discarded tools removed from it. The number of tools on inventory should at all times correspond with the sum of the number of tools and workmen's checks,

representing tools, in the toolroom. The inventory should be checked on a regular program by counting tools in the successive sections of the toolroom, in sequence as opportunity offers, the entire toolroom to be covered at intervals of from 3 to 6 months.

The methods for keeping a perpetual tool inventory do not differ in principle from those that apply to perpetual inventory of stores.

Tooling Developments

TOOL ENGINEERING.—Tool engineering is now a large field of specialization in which there is a constant trend toward improved methods which have far-reaching effects on production. The technical elements of the subject are the concern of the tool engineer. The production man, however, should be alert to the possibilities that affect his work. Therefore in this section are briefly indicated certain lines of developments which are bringing about increased production, greater tool life, higher quality of work, and better control over quality.

CEMENTED-CARBIDE-TIPPED TOOLS.—Fred W. Lucht (Mech. Eng., vol. 66), in discussing the elements to be considered in milling steel, points out that delays in successfully applying cemented-carbide-tipped tooling for this purpose have been caused by the fact that processing was carried on in exactly the same manner as with high-speed steel cutters in the past. With cemented-carbide-tipped tools, rigidity of set-up, high power, the proper cutting speed, and the proper tooth loading are of even greater importance than with high-speed steel cutters. He states:

It was also found that the positive cutting angles which are used for high-speed steel cutters for milling steel were really fatal with cemented carbides, and slight progress was made until it was known how to apply cemented carbides properly to single-point tools for turning, facing, and boring interrupted cuts. This resulted in the use of the proper combination of positive and negative cutting angles and gave the first real clue to the successful application of cemented carbides to milling steel, because all milling cuts are interrupted cuts due to the nature of this type of machining operation.

On all cutting tools the proper combination of the side-cutting-edge angle (bevel angle on milling cutters), back-rake angle (axial rake angle on milling cutters), and the side-rake angle (radial rake angle on milling cutters) has a direct bearing on tool life since these three angles control the amount of protection afforded the cutting edge and the nose radius or chamfer. The latter is usually the weakest portion of any cemented-carbide cutting tool and must receive maximum protection. It is doubly important to protect the nose radius because it also maintains the size on the cut.

A general requisite to be remembered in applying cemented-carbide tools to interrupted cutting (milling) operations is to build up sufficient back pressure through the design of the cutting tool to prevent the tool from digging into the cut in any direction and also to absorb all backlash in the machine before the nose radius or chamfer on the tool enters the cut. Failure to observe this simple consideration may be the cause of much unnecessary tool trouble.

A diagram giving Lucht's nomenclature for milling cutters with cemented-carbide tips is shown in Fig. 16.

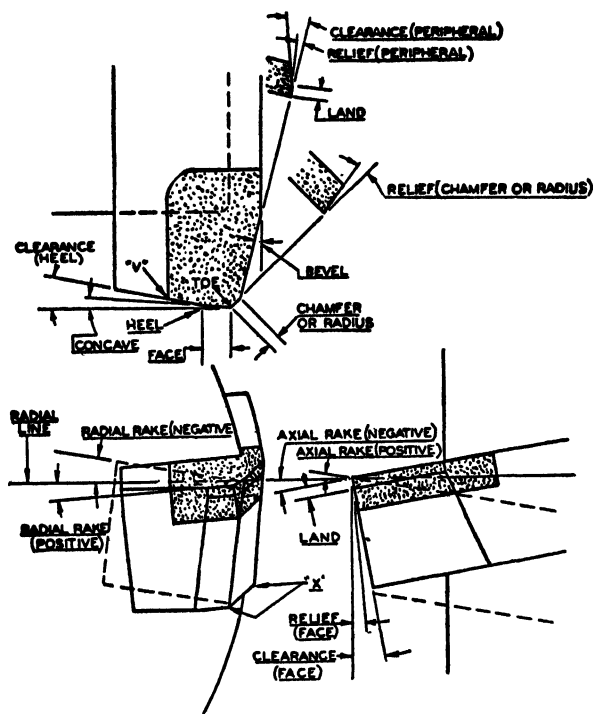



Fig. 16. Nomenclature for Milling Cutter with Cemented-Carbide Tips

Recommended Practice in High-Speed Milling.—Einar Almdale (Mech. Eng., vol. 66) indicates that if machine horsepower is not sufficient, cutters should be designed so that the proper chip load may be obtained, a practical rule being to use a cutter with from one-fourth to one-half the usual number of teeth and twice the body thickness.

Recommended practice, evolved under the experiences of the Carboloy Co., for adopting high-speed milling is:

1. Not to tool up all machines at once with carbides.
2. To make the first applications on a few simple surfaces, such as facing cuts.
3. Not to attempt difficult jobs until experience is obtained on the simple jobs.
4. To use a fly cutter-single-toothed cutter easily altered and ground for a particular job—in establishing cutter specifications for a specific complicated job.

Results secured under the above methods:

1. Workers become accustomed to higher speeds and get the "feel" of high production cutters.
2. Grinding-room personnel have time to acquire proper grinding technique.
3. Fixture designs may be developed. Flywheels may be put on the spindles to smooth cutting action by overcoming the effect of backlash in spindle and gears. An air blast or heavy stream of coolant may be required to clear chips from cutter to prevent rapid tooth breakdown.
4. Use of a fly cutter determines correct rakes, tip thickness, grade of carbide, chip load per tooth, and optimum speed for such jobs.

Reducing Power Requirements with Negative Rake Angles.—Under the usual cutting speeds with high-speed steel cutters the power required to remove metal increases greatly as the conventional positive rake angle is decreased, being over twice as great with a zero angle as with a 45° angle, as shown by repeated tests. A negative rake angle apparently would increase the power required and actually does so at low cutting speeds, but at high speeds the power steadily decreases with increase in speed and beyond a certain speed may approach the lower power consumption of large positive rake angles (Ernst, Mech. Eng., vol. 66).

Experiments of the Cincinnati Milling Machine Co. showed that the point at which the negative-rake-angle tool required less power than the corresponding positive-rake-angle tool occurred at lower and lower cutting speeds the greater the feed used, inches per revolution, because of a reduction in both coefficient of friction and force of friction between the sliding chip and the tool face.

It is very important to exercise great care in the preparation and maintenance of cutters and in grinding. The grinding wheel—preferably diamond impregnated, 100-grit for roughing, 400-grit for finishing—must be rotated against the tooth being ground so that the grits approach the cutting edge from the face of the tooth, to avoid overheating. Not over .0003 in. of carbide should be removed per pass for roughing, and .0001 to .00015 in. per pass for finishing. A pad soaked with kerosene or very light oil should bear against the wheel. Tool damage must be fully eliminated in the grinding, and carbide-tipped cutters should be reground when only slightly worn. The ground edges should always be inspected with a low-power microscope.

Developing Tools for Greater Efficiency.—Examination of long, curling chips from milling operations shows discoloration usually only on the side away from the tool, indicating that most of the heat is concentrated, and perhaps generated, there. Quick removal of chips therefore removes much of the heat away from the tool and the work. Tool research conducted at Bell Aircraft Corp. on aluminum castings and other alloys (Schwartz, Mech. Eng., vol. 66) substantiates the fact that increased speed of cutters with a reduced number of teeth may be attended by a **reduction of heat** except in the case where all other conditions change directly in proportion to the speed. Apparently a sliding tooth generates as much heat as a cutting tooth, and a light cut under a low feed produces almost as much heat as a cut perhaps five times as heavy.

TOOL-LIFE TESTS.—Since many metal-working companies interested in tool economy carry on tests to determine tool life, the American Standards Assn. Technical Committee 21, through its Sectional Committee B5 on the Standardization of Machine Tools and Machine Tool Elements, has developed a proposed standard of tool-life tests for evaluating the machinability of single-point cutting tools, cutting fluids, or materials cut. Professor Boston (Mech. Eng., vol. 66), chairman of the Sectional Committee, presents data of which the following is a brief summary. The methods covered are those for tools of steel and cast nonferrous alloys, which fail or wear differently from tools with cemented-carbide tips.

1. Single-point tools may be solid or tipped with a small piece of metal-cutting material.
2. Outline of a test must cover the objective—performance rating of tool, material cut, or cutting fluid—method of test, factors and apparatus used, and method of analyzing data and correlating them with actual shop conditions.
3. Merits of a tool, metal cut, or cutting fluid may be based singly or collectively on: tool-life cutting speed relationship, surface quality produced, form of chip produced (well-broken-up chips are best), and forces, energy, or power involved.
4. Cutting conditions should be as near as possible to actual conditions, to determine the four factors in item 3. Such conditions may be: light, intermediate, and heavy cuts on abrasive materials or one giving discontinuous chips, as cast iron; the same on steel of several types and structures; tools, cuts, and materials for general purpose work; cuts, tool materials, cutting materials for specific commercial practice.
5. Variable factors involved are the machine tool—type, condition, capacity or size, method of power transmission, speeds, feeds, and tool mounting and work holding means; material cut—analysis, structure, hardness, strength; tools—material composition, physical condition, scale or surface condition, shape and rigidity under continuous and intermittent cutting, as-forged or as-cast or as-rolled (cleaned, pickled, blasted, hot-rolled, or cold-drawn), heat treatment, kind of tip and method of attachment if tip is different from shank, and shape of tool point; cutting fluid—class, properties, and methods of manufacture; size of cut (depth and feed) and its shape.
6. Methods of test for cutting-speed tool-life relationship should involve but one variable at a time, all other factors being kept constant, and a number of standards should be set up to determine this relationship. For tool material tests, for example, the factors to be kept constant are tool shape, depth of cut and feed, setting angle of tool, analysis and heat-treatment of material being machined, and type of cutting fluid (including dry cutting).

Size of cut must be varied—light, intermediate, and heavy—to give specific tests under commercial conditions attending the use of the tool. Feed is represented in thousandths of an inch per revolution of work or cutter. Suggested cuts are:

1. .005 to .010-in. depth of cut and .002-in. feed.
2. .100-in. depth of cut by .0125-in. feed.
3. ⅛-in. depth of cut by .020-in. feed.
4. 3/16-in. depth of cut with .005-in. or .010-in. feed.
5. Maximum of ¼-in. depth of cut with .03-in. to .05-in. feed.

Cutting speed is measured on uncut work surface ahead of tool, and recorded in feet per minute.

The two general methods for obtaining machinability ratings based on tool life are:

1. To obtain tool life when cutting under standardized conditions at a constant cutting speed, as in turning cylindrical test bars.
2. To obtain tool life when cutting at a uniformly increasing speed, as in facing.

The formula for expressing the relation between cutting speed and tool life between grindings for a given tool, material, feed, and depth of cut (method 1, above) is:

$$V T^n = C$$

where V = Cutting speed, in ft. per min.
T = Tool life or duration of cut between grindings, in minutes
C = A constant, depending on conditions, and is the cutting speed for a tool life of 1 min.
n = The slope of the tool-life straight line on log-log paper.

In Fig. 17 are shown the results of cutting-speed tool-life tests on two die steels, both heat-treated and tempered to give a Brinell hardness of 363.

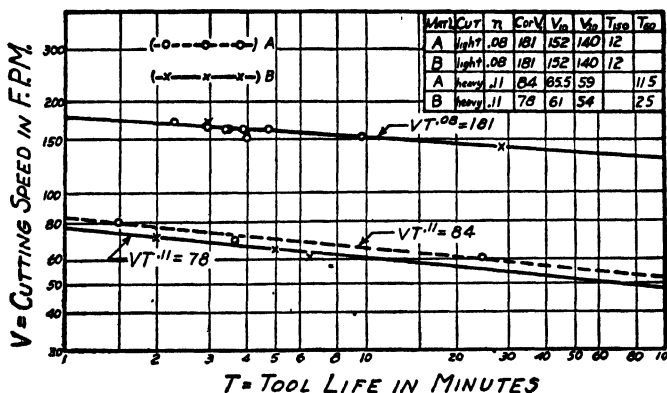



Fig. 17. Tool-Life Cutting-Speed Relationship in Turning Two Forged Die Steels Designed as "A" and "B"

NOMOGRAPH CALCULATIONS FOR SPEEDS, CUTS, AND POWER.—Nomographs have been developed to include the basic idea of Taylor and Barth slide rules in balancing horsepower against tool life and also to include modern materials and to be applicable on geared-head motor-driven equipment as well as belt-driven tools. They apply to cutting steel with single-point tools (see Fig. 18). Surface finish has not been correlated with the other variables. The variables of machinability included are:

V = Cutting speed, ft. per min.
T = Tool life, min.
K_{tm} = Constant for tool life, depending on tool material
K_{mc} = Constant for tool life, depending upon material cut
f = Feed, in. per rev.
d = Depth of cut, inches
C_{Bhm} = A constant of tool force, depending upon Brinell hardness of material cut

Tool-Life Determinations.—Graphs of cutting speeds versus related tool life for different tool materials are plotted on log-log paper as straight lines (see Fig. 17) and are expressed by the equation $VT^n = C$, an average value of n for normal work materials and cuts being .125. These straight-line curves are plotted for different kinds of tool materials—carbon tool steel, high-speed steel, cast cobalt-chromium-tungsten alloys, and cemented carbides. Tool-life ratings vary with the quality of tool design, with vibration or chatter, etc. By cutting different materials of known Brinell hardness with a tool of any specified kind of tool steel the cutting speed for an identical tool life in each case may be calculated and plotted as curves on a cutting-speed vs. Brinell-hardness graph. If reduction of area is considered, the cutting speed, for a definite tool life, may be more accurately predicted, Janitzky (Trans. A.S.M.E. vol. 26) showing this relationship to be $V_{60} = \frac{C}{B^{1.63}\,R^{1.01}}$, where B is Brinell hardness and R is per cent reduction of area.

Graphs of cutting speeds versus inches feed or depth, that is, size of cut, for a definite tool life, plotted on log-log paper are straight lines and are prepared from tests keeping the tool material and the material cut constant. The equation for such plots is $V_{90} f^{.61} d^{.36} = K$. Doubling depth of cut reduces speed only 22% but rate of metal removal is 56% more. Doubling feed reduces speed only 34% but rate of metal removal is 31% more.

Tool shape in the nomograph has been corrected to a tool having 8° back rake, 14° side rake, 6° end relief, 6° side relief, 6° end-cutting-edge angle, 15° side-cutting-edge angle, and 3/64 in. nose radius. Increasing nose radius or side-cutting-edge angle may increase tool life or increase cutting speed as much as 50%, except perhaps on cemented-carbide tools. A rake angle of 20° to 30° is best when cutting soft, ductile steels, 0° to 10° for hard, brittle steels.

Cutting fluids (the nomograph is based on dry cutting) may increase cutting speed 15% to 30% in the case of emulsions, 10% to 25% in the case of oils if long tool life is important.

The tool-life nomograph, left half of Fig. 18, including "Feed—inches per revolution," was constructed on the basis of $VT^{.125} = \frac{K_{tm}\,K_{mc}}{f^{.61}\,d^{.36}}$. All scales are logarithmic. With 5 variables known in this half of the diagram, the sixth may be found. By pivoting the long dash line on the point where it crosses line C, the effect of changing feed on the velocity of cutting may be checked. As feeds decrease, speeds would go up but the amount of metal removed would be reduced.

Tool Force Determinations.—Tool forces in the tests showed no appreciable variation among tools of different materials, except that as

tools dulled, the tangential force decreased slightly, and at tool failure the force may double. Similarly, in a test conducted at the Consolidated Aircraft Corp., Vultee Field Division, no change in load resulted as surface velocity changed, for speed variations within the test range of 200 and 1,500 ft. per min., under various feed combinations from light to heavy (Brainard, Mech. Eng., vol. 66). A 35% allowance was made in the nomograph to allow for tool dulling and failure and consequent danger of machine stalling and tool breaking. Tool force varies with material cut, being higher with plain carbon steels, for which the nomograph is designed, than with free-cutting steels, for which the power requirements will be about 40% less. For an average slope of .75 for straight-line curves on log-log tangential-force versus Brinell-hardness number charts, the tangential force equation would be $F_t = K(Bhn)^{.75}$.

Feed and depth increase in cuts has practically a direct effect on horsepower or tangential tool force. With tools of the larger radii, the tangential-force equation is $F_t = Cf^{.8}\,d^{.9}$, showing that it is beneficial to increase feed or depth by reducing cutting speed—the tangential force increasing but the power for removing a unit amount of metal decreasing.

Larger nose radii or side-cutting angles have no appreciable effect on tangential tool force but would affect radial and longitudinal tool force. With higher rake angles tool forces and power are reduced. Rake angles below 14° require more power (Boston and Kraus, Trans. A.S.M.E., vol. 58).

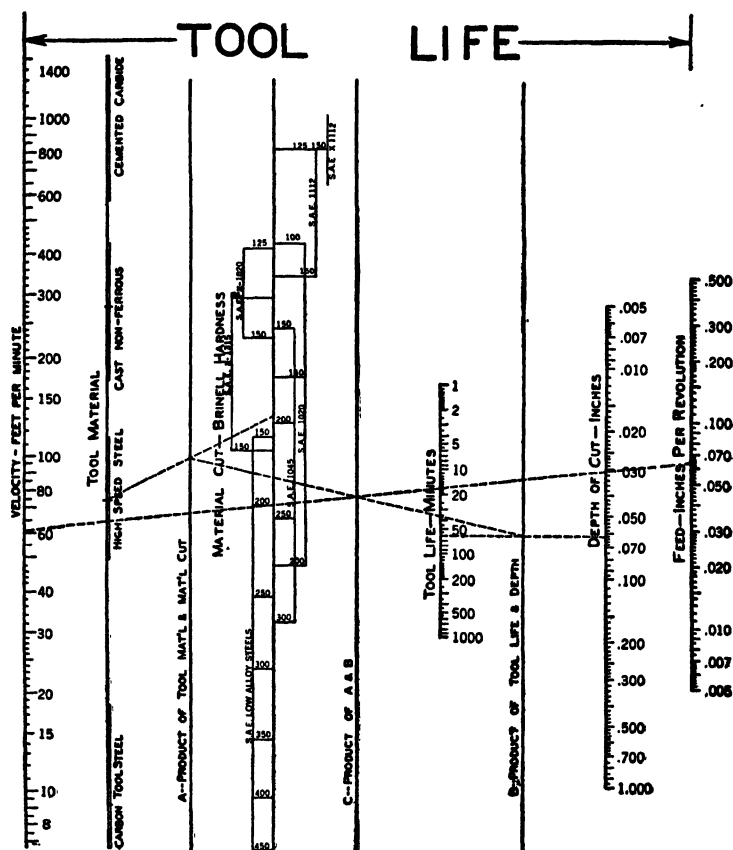
Cutting fluids, useful in reducing tool forces, have little effect on tangential force or power at high speeds but may reduce power at low speeds.

The equation for power requirements is

$$\text{Motor horsepower} \times \text{Efficiency} = C_{Bhn}\,f^{.8}\,d^{.9}\,V$$

With 5 variables known in the right half of Fig. 18, including "Feed—inches per revolution," the sixth may be found. The power requirements will exceed those from many other methods of calculation because they include the 35% allowance for tool dulling.

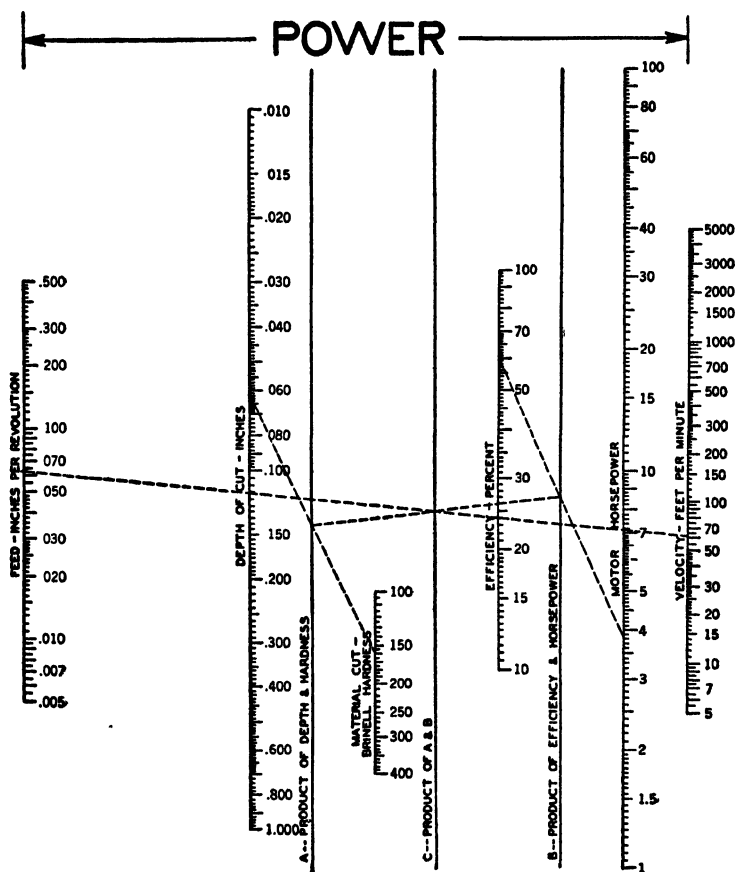
Maximum Output.—The combined tool-life and power nomographs in Fig. 18 are used to determine maximum outputs. The authors state:

High machine output is obtained when heavy cuts are used. This nomograph will indicate that heavy feeds are desirable; the largest feed possible consistent with the strength of the cutting tool, the material cut, and the machine tool, should be used. An acceptable surface finish may also limit the amount of the feed. When the feed is increased, it will cause a decrease in allowable cutting speed on both the tool-life and the power scales. The smaller of these two values of cutting speed should be used. Caution must be exercised in choosing the size of cut when operating a high-powered machine. Heavy cuts may break the cutting tool, the machine, or the work. Chatter may also occur if there is insufficient rigidity, and this may cause premature tool failure.

SAMPLE CALCULATIONS—TOOL LIFE

Given:
Tool material .... High speed steel
Material cut .... 160 B.H.N. — S.A.E. 1020 steel
Desired tool life........... 60 min.
Depth of cut.............. .0625 in.
Feed .... .0625 in. per rev.
Read from chart:
Velocity = 60.5 ft. per min.

MAXIMUM OUTPUT

Given:
Tool material
Material cut
Tool life
Depth of cut (Deepest cuts most efficient)
Machine efficiency
Motor horsepower (Use rated horsepower)

FIG. 18. Combined Tool-Life and Power Nomograph (Calculations
(Gilbert and Truckenmiller, Metal Processing

Sample Calculations—Power

Maximum Output

The feed should be varied until the velocity on the Tool Life side is equal to the velocity on the Power side. This feed and speed will give the maximum metal removal for the given conditions.

Given:

Feed	.0625 in. per rev.
Velocity	60 5 ft. per min.
Depth of cut..............	.0625 in.
Material cut	160 B.H.N. — S.A.E. 1020 steel
Machine efficiency	60%

Read from chart:

Motor horsepower = 3.75

based on studies of a single-pointed tool under dry cutting)

Dept., Univ. of Michigan, Mech. Eng., vol. 65)

Sample calculations of tool life and power are given on the nomograph. The following example, which may be worked out on the combined nomograph, illustrates its use to determine maximum output of an engine lathe.

Given:
- Material cut, S.A.E. 1020 steel, B.h.n. 160
- Tool material, cemented carbide
- Desired tool life, 240 min. (4 hr.)
- Depth of cut, .200 in.
- Machine efficiency, 60%
- Motor horsepower, 20

Find:
- Feed and velocity for maximum output
- Vary the feed until the velocities on the tool-life side and the power side of the combined chart are equal.

Read from chart:
- Feed = .019 in. per rev.
- Velocity = 280 ft. per min.

If the feed were increased beyond .019 in. per revolution, it would be necessary to reduce further the cutting speed to prevent overloading the motor. The tool life at this reduced speed would be more than 4 hours

The main application of the combined nomograph is that many of the laws of tool life and power are incorporated in one simplified chart which is easy to use. The cutting speeds obtained by the nomograph are conservative, but should materially assist in estimating the speeds and feeds for giving higher production rates.

In the "Manual on Cutting of Metals" of the American Society of Mechanical Engineers extensive data are given on the calculation of cutting speeds and horsepower required for feeds varying from .002 to ⅛ in. each, for nine depths varying from 1/32 to 1 in. Data from the machining of 35 commonly used steels by seven kinds of tools—four roughing, one finishing, one parting, and one forming—are also included. The information was compiled by research covering a period of 5 years.

CUTTING TOOL STANDARDIZATION.—Investigations carried on at the Wright Aeronautical Corp. showed that complicated and expensive machine tools will not be profitable if the single-point tools used in the tool set-up are improperly designed and applied. High-speed steel cutting-tool life can be greatly improved by the combination of correct design, proper tool set-ups, and fine tool finish (Wiberg, Mech. Eng., vol. 65).

Design.—In designing the proper width and angle of tool, the important factors to consider are surface speed, feed, depth of cut, and type of material being cut. The step-type chip-breaker tool was selected for study as superior to the tool without chip breaker or with the groove-type chip breaker, from the standpoint of satisfactory chip formation and tool life. After testing ten different tools the design chosen was that of a parallel chip breaker with no back rake. Selection was made upon the basis of tool life, surface finish, power consumption, chip formation, simplified grinding, and design. Fine finish was given to the tools (4–8 microfinish) as it was found to increase tool life about 85% over that of tools of identical design but with ordinary finish (60–80 microfinish).

Grinding.—Production grinding was adopted in place of hand grinding to obtain the precision, efficiency, and economy required in the complete

set-up. Tools are ground in a central grinding room, eliminating all grinding by machine operators, who are instructed to return used tools to the crib before complete breakdown and replace them with new tools. Central grinding has improved tool life 6 to 1 over operator-ground tools. After being ground and inspected to blueprint dimensions by means of gages the tools are put in suitable individual cartons to keep fine finishes and keen cutting edges from damage. They are then delivered to tool cribs at convenient positions on the shop floor, from which they are distributed to operators, who obtain them by stating style number, size, and nose radius (see later), as for other kinds of standard tools.

Four Classes of Standards.—In the final standardization of tools four classes of tools were set up as standards: turning, facing, boring, and chamfering. Number of tool-shank sizes was held to seven for turning and facing, six for boring, five for chamfering. Nose radii were limited to seven values between .030 and .250 in. Tool-holder-slot angles were selected at intervals of 5° between 0° and 90°, to provide tools for the existing tool blocks, but with the plan of reducing the number of slot angles in obtaining new equipment.

The standards were made up in book form under the four classes above, and include instructions for selection of tool, tool-position sketches, and tool-selection tables. Each tool was given a T number and style number. A blueprint was made for each T number, applicable to solid or typed tools with step-type chip breaker and fine finish (4–8 μ in.). The style number for each tool in the standards was derived from the two main cutting angles and has no relation to size of tool. Thus: S 15–25 is a side-cutting tool (tool with principal cutting edge on side, including all tools having side-cutting angle of 0° to 45°) having a 15° side-cutting angle, 25° end-cutting relief angle; E 15–25 is an end-cutting tool (tool with principal cutting edge on end, including all tools with end-cutting edges of 0° to 45°) having a 15° end-cutting angle, 25° side-cutting relief angle.

Standards for Carbide-Tipped Tools.—Carbide-tipped tools were standardized along lines similar to those for high-speed steel tools, including standards books with instructions for tool selection, tool-position sketches, and tool-selection tables. Nose radii have only five values between .015 and .120 in. Chip-breaker design was divided into two types: 8° angle step type in 1/16, 3/32, 1/8, and 5/32-in. widths; parallel step type in 3/32, 1/8, 5/32, and 3/16-in. widths. The tungsten-carbide-tipped tools were applied to cutting steel, aluminum, magnesium, brass, and bronze and were purchased in seven standard stock styles to make approximately 26 tool styles. The four grade specifications for machining steel and four grades for cutting nonferrous metals were:

1. Majority of roughing and finishing operations.
2. Light-finishing cuts where ability to hold size is important.
3. Intermittent cuts.
4. Precision boring.

TOOL FINISHING.—Tests made on grinding at the Norton Co. (Ericson, Mech. Eng., vol. 66), employing a fine-grit, freer-cutting, finish-grind shellac wheel, showed that about the same time was required to get a fair edge on regular grinding wheels under the former

procedures as was needed to mount the proper finer-grit wheels and obtain the better results with special finish grinding. It is the practice, therefore, to assemble a number of tools to be ground, so that one change of wheel from rough to finish grind will take care of the entire lot. On regular 46- and 60-grit wheels a smoothness of 20 to 30 μ in. rms., on the average, as measured by a profilometer, may be obtained on tools of various metals. More skilled grinders obtain 8 to 12 μ in. rms. Fine-grit finish-grinding wheels give 2 to 5 μ in. rms.

Other factors, besides kind of abrasive and grit size in wheel or honing stick, which affect finish of the tool (Wise, Am. Mach., vol. 85), are strength of bond in the abrasive body, dressing of the wheel, skill and method of the grinder, rigidity of set-up, and properties of tool material. Use of a grinding coolant is also helpful. Finer finishes are obtained with harder tools and harder wheels. Finishing wheels should be used only for finishing. If used for roughing they wear too fast and overheat the tools.

Improvements Brought About.—In one plant, properly ground reamers 1½ in. in diameter used to machine No. 21 aluminum castings were found to last for two to three days without resharpening, as compared to a half day before. The reamers thus were resharpened only 1/5 the former number of times, increasing the life of both reamers and grinding wheels, besides saving grinding time, shutting down production only 1/5 as often, and producing a better finish.

In another plant large hobs for cutting large reduction gears were found to be burned back so little under use when properly sharpened that only .010 in. had to be ground off instead of .060 in. as formerly. Time of grinding was cut from 17 hours down to 5 hours, finishes were better, and cutter life was considerably increased. In the same plant finish-milling cutters on work requiring extra-fine finish were able to do the operation in 6 hours instead of the former 16 hours because of the keener cutter edges produced by the better grinding methods. Previously work had to wait until cutters were sharpened, and a cutter would mill only part of a piece when it would have to be removed for grinding; after the proper grinding wheels and procedures were introduced, cutters were ready ahead, one cutter finished the piece without regrinding, and work stoppages were eliminated.

Records of research tests on the improvement of finish grinding practices were kept and the following advantages were proved:

1. Longer life of cutters because resharpenings were fewer.
2. Fewer grinding wheels used.
3. Increase in work between regrinds. Tests showed from 9% to 300% increase.
4. Less power consumption.
5. Better quality of work produced.
6. Cutter teeth of uniform height.
7. No holdup in production in waiting for tools to be sharpened.

CUTTING FLUIDS.—Since cutting fluids have a decided effect upon tools and the machining of metals, the Subcommittee on Cutting Fluids of the Special Research Committee on Cutting of Metals of the American Society of Mechanical Engineers made extensive studies of this subject (Boston, Moir, Slaughter, Oldacre, Mech. Eng., vol. 65).

The recommendations cover practices under the use of high-speed steel tools. Tables for the proper selection of cutting fluids are included. Some of the conclusions and recommendations are:

1. Mineral-lard oil and sulphurized-oil mixtures of low sulphur percentages, in general, are interchangeable.
2. Sulphurized oils have a tendency to stain certain nonferrous metals, such as copper and its alloys.
3. Certain materials, such as carbon tetrachloride, chloroform, and other volatile solvents should not be added to cutting fluids because of possible harmful physiological effects.
4. In machining aluminum, cutting oils may be diluted with kerosene or mineral seal oil, with satisfactory results. Kerosene up to 15%, added to emulsions, improves the surface quality of machined aluminum.
5. Magnesium and its alloys are usually machined with mineral seal oil, except where dry machining is desirable. Tools should be kept sharp, heavy feeds used, chips promptly removed. Fire hazard is high. Powdered asbestos or graphite, or an extinguisher known as G-1 powder, should be kept handy to smother any fire.
6. In machining brass, a cutting fluid for cooling purposes is beneficial, and, for automatic screw machines, a paraffin or light mineral oil, plain or blended with 10% fatty oil, may serve at the same time to lubricate the moving machine parts.
7. In turning Monel metal, an emulsion gives longer tool life than a sulphurized mineral oil, but the latter is good to produce broken-up chips, which is often desirable.
8. Cutting fluids, 3 to 5 gallons for each single-point tool, should be applied at the highest velocity obtainable without splashing, directly onto the tool point. Flow should start before tool cut, particularly with carbide tools, and should be continuous during the cut. Rapid temperature change is injurious to most tools.
9. Temperature of cutting fluids should be held to 110° F. as a maximum, by sufficient volume of circulation or use of cooling agencies.
10. Cutting fluids should be kept clean, and free from suspended chips, bacteria, and high acidity.
11. Oil should be used to lubricate moving parts, such as tool slides, on complicated machines. Chip removal from milling cutters, drills, etc., should be facilitated by lubrication in flutes or chip spaces.
12. On high-speed operations cooling is more important than lubrication, speed often assuring good surface quality. On low speeds where discontinuous chips are formed, the tool face may need lubrication, and oils—particularly a sulphurized oil for threading and broaching—are desirable.

MASTER TOOLING.—Master tooling has had rapid and wide development, especially in the aircraft industry. It is used primarily to guarantee interchangeability for mass production. Watson (Mech. Eng., vol. 66, No. 1) points out that master jigs also make it possible to use partially skilled help in the fabrication of assembly tools, which becomes a matter of lifting points and surfaces already established by the master. He designates five classifications, as developed at the Douglas Aircraft Co., under which master tools fall:

1. Master diagram, with all basic critical dimensions calculated from engineering data and charted for design of master tools.
2. Master layout, in which engineering data, tooling data, tooling hole locations, and coordination data are combined.

3. Master "plaster" (Hydro-Cal) patterns, used for all fabricating data on compound surfaces.
4. Master jigs, for fabrication of assembly jigs.
5. Inspection fixtures, or inspection "gages," used to inspect parts or assemblies to guarantee interchangeability, and necessary because various subcontractors in different localities were supplying assemblies.

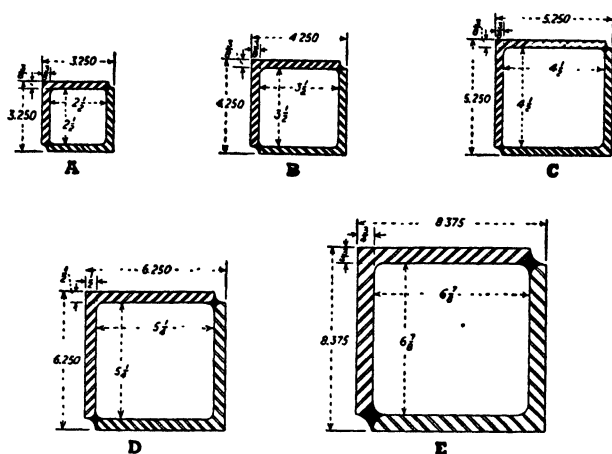
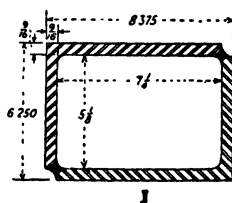
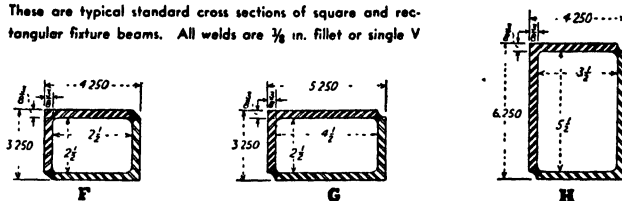
The simplest master tools are those used in simpler forms of fabrication, to assure mating of surfaces. More complicated types combine matching surfaces with compound surfaces to be duplicated, to simplify the fixtures and guarantee interchangeability of the entire structure. For mass production, master devices are necessary so that all parts can be set and attach points located. Finally, there is a control master, or a master to build masters, where work is done in more than one location. The control masters, which never leave the main plant, are used to fabricate the original master and then, in case of damage to this latter master, to permit the critical points to be reset.

STANDARDIZATION IN TOOLING JOBS.—The Lockheed Aircraft Corp. devised a plan of standardization on major jig design. Boden (Mech. Eng., vol. 66) states that this step was taken to cut down the time of designing major jigs and master tools, and, by turning out designs familiar to jig builders, enable them to perfect a repetitive building technique, thus speeding up the manufacture of the tools.

A manufacturing standards manual was developed in which all the structural data for a proper analysis of tools were compiled (see Fig. 19). A single-beam construction and a standardized box beam were adopted, built up from structural angles, intermittently welded and with surfaces machined. A tool draftsman, developing a jig from such standard elements, secures a brown line-print by number from the department's filing section, fills in legend, dimensions, and detail number and sends the print for the structural detail to the welding shop where the part is fabricated, normalized, and machined, after which it is sent to the tooling department.

The typical single-beam jig used is approximately 300 in. long, but with standard extensions can be satisfactorily extended to 500 in., and is simple, very accessible, and stable. Measurements have shown that such jigs, after a week's use, do not go out of alignment more than .005 in., thus reducing mastering to a minimum. Beams, joining plates, and standard locators are 90% to 95% salvageable.

In the Douglas Aircraft Co., Santa Monica Plant, on the other hand, welded angle-iron and channel and I-beam structures have been used for practically all of the basic structures for major assembly jigs, the cost per pound being lower. At first, for salvage purposes, tack-welded joints were used, but data collected showed that, in the long run, it was cheaper to scrap the steel. The total cost of the tool, including scrapping the steel, under this plan, was less than under other methods of tooling.

FLEXIBLE TOOLING.—The need for rapidly developed low-cost but closely accurate devices for interchangeable quantity production and progressively changing design of parts has given rise to use of equipment and methods for flexible tooling: cast plastics, forming-by-drawing machines, stretch press, drop hammer, power brake, rubber press, and Kirksite, Masonite, and wood dies.

SECTION PROPERTIES

	Lb /Ft	Area In^2	Ix In^4	Iy In^4	X In	Y In
A	13 7	4 04	6 1	6 1	1 625	1.625
B	18 9	5 54	14 4	14 4	2 125	2 125
C	23 8	7 02	29 2	29 2	2 625	2 625
D	37 4	11 00	62 5	62 5	3 125	3.125
E	75 0	22 12	225 0	225.0	4 188	4 188
F	16 3	4 78	11.9	7 5	1 625	2 125
G	18 8	5.52	20 2	9.2	1 625	2.625
H	23.8	7 02	37 6	21 0	2 125	3 125
J	50.0	14 7	140 0	88.0	3 125	4.188

FIG. 19. Welded Sections for Members in Assembly Jigs
(G. A. Betts, Lockheed Aircraft Co., Am. Mach., vol. 87, No. 17)

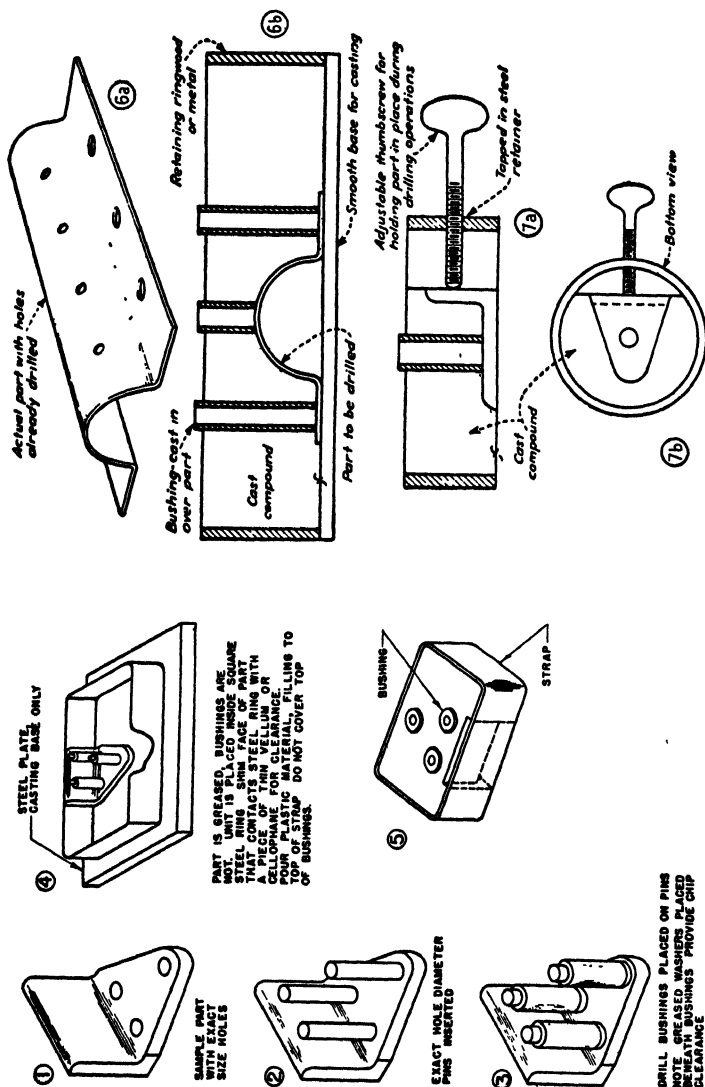



FIG. 20. Drill Jigs Made from Plastics

Cast Plastics for Tooling.—Plastic tools are those made by casting a material around a shape or part with the aim of developing a device to reduce finishing or completion operations to a minimum. This method increases the flexibility of tooling and seems to be applicable to about 10% of traditional tools. It is particularly beneficial in getting into production quickly—Lockheed having cut down time three months by this method in getting the B-17 bomber into manufacture—and when frequent changes in models occur, as in the aircraft industry, the use of more expensive tooling would not be justified. Reporting on work done at the Brewster Aeronautical Corp., Weiss (The Use of Cast Plastics for Aircraft Tooling, Inst. of Aeronautical Sciences, 12th Annual Meeting) points out that:

1. Plastics may be substituted for wood, steel, Kirksite, concrete, and similar tool materials, in many cases.
2. Tools may be cast to a satisfactory master part, model, or mold more quickly than by forming, milling, or hand fitting.
3. Temporary tooling may be quickly made for rush jobs, or to get a job into production rapidly without waiting for the permanent tools to be finished. Sometimes the temporary tools are found to be sufficient for the entire production requirements.
4. Duplicate tools to increase the rate of production may be fabricated at less cost than the original because of the fact that the molds can be saved.
5. Duplicate tools can be made more economically and quickly for transportation to other plants, or to subcontractors, thereby insuring accuracy of the work in those places.
6. Experimental design models may often be made more quickly and cheaply if plastic tools are developed to build the prototype, and may be used to make a limited quantity of additional units, if desired, while the model is being assembled.

Materials Used.—The plastic materials used include thermoplastics which may be softened and hardened repeatedly by application of heat and cold, without any basic change of behavior, or melted and reclaimed for other uses; thermosetting resins which are softened during the original heating and hardened by a continuation of the application of heat, but cannot be altered or reformed by heat and are nonreclaimable; cold-setting plastics, really thermosetting in character, and composed of inorganic and/or organic materials in powder form mixed with a liquid accelerator generating heat and causing the material to cure without being baked in an oven, but making it nonreclaimable; inorganic cast compounds, plasters, low-melting-point alloys, and materials of a similar nature. Fillers are generally added, such as fibre, cloth, asbestos, etc. Reinforcement is used where necessary.

The procedure of making drill jigs from plastics is indicated in the illustrations in Fig. 20. The part to be drilled is used as the model. It is set on a smooth plate as a casting base, bushings are set in place, a steel, wood, dural, pipe, angle-iron, or other retaining ring or retainer is put around it, the plastic is poured, and when it has set the jig is ready.

Applications.—Applications may be subdivided into the following groups:

1. **Forming operations**
   a. Form block—rubber pad press
   b. Stretch press dies
   c. Form block—hammer
   d. Draw dies—male and female mating
   e. Drop hammer punches
   f. Tube bending forms
   g. Mandrels for plywood
   h. Dies for forming plastic sheets
2. **Cutting operations**
   a. Drill jigs
   b. Routing fixtures
   c. Saw-cutting fixtures
   d. Lathe fixtures
   e. Milling fixtures
   f. Keller machine models
   g. Imbedded cutting knives
   h. Blank and pierce dies
   i. Countersinking fixtures
3. **Assembly and checking operations**
   a. Assembly fixtures
   b. Checking fixtures
4. **Miscellaneous operations**
   a. Dies for vulcanizing rubber
   b. Rubber dip form
   c. Injection dies for molding plastics and similar substances
   d. Thermosetting molds — cast and compression
   e. Dies for cold-molding plastics
   f. Welding jigs
   g. Surface plates
   h. Buffing holders
   i. Sand-casting patterns
   j. Apply templates

In subdividing tools for plastics applications it is advisable to separate them into tool types:

1. Conventional tools which can be satisfactorily replaced by plastic tools, size for size, with no change except materials.
2. Present tools which are satisfactory for use as designed.
3. Conventional tools which require extensive redesigning before plastics can be utilized.
4. Conventional tools not satisfactory for replacement at the present time.

Methods of Producing Tools.—If plastic tooling is adopted, the user must decide whether enough such tools are to be made to justify manufacture, or whether contracts should be given to a vendor producing such tools. A plastic-tool shop needs adequate area; water, power, air, steam, and temperature-control services; a good weighing scale, buckets for handling raw materials, a supply of hand tools, and a rigid table—straight and level—marble or slate being satisfactory, for small castings. The remaining equipment varies with the process:

1. Thermoplastics require simple mixing equipment with heating elements. Controlled temperatures must be maintained. The plastic cures on cooling.
2. Thermosetting compounds are mixed at room temperature but must be heated in an oven for a specific time, after pouring, to cure properly.
3. Cold setting compounds are mixed at room temperature in an ordinary mixer. In some cases vacuum equipment can be used to advantage.

Quantity and technique in preparing plastic materials is equally as important as the kind of resin used.

Plastic tools can be sanded and polished by usual means, or patched and reworked, in many cases, by using the basic material.

Checking on Materials.—Figures given out on the various physical characteristics by the manufacturers should be checked before using the plastics because they are subject to variation in the lots of material actually received. Checking of the following properties will aid in the selection of plastics for given applications:

1. Type of plastic—thermoplastic, thermosetting, cold setting
2. Specific gravity
3. Specific volume
4. Tensile strength
5. Modulus of elasticity
6. Compressive strength
7. Flexural strength
8. Shear strength
9. Thermal expansion
10. Resistance to continuous heat
11. Pouring temperature
12. Distortion under heat
13. Tendency to cold flow
14. Water absorption
15. Combustibility
16. Effect of:
    - Age
    - Sunlight
    - Weak acids
    - Strong acids
    - Weak alkalies
    - Strong alkalies
    - Organic solvents
17. Abrasion resistance
18. Effect on metal inserts
19. Machinability
20. Castability
21. Grades available
22. Recommended uses

Costs.—Since plastic tooling allows of simple basic tool design—most castings being made from a sample part or model—design costs usually are not high. In some cases, however, the design and making of the tool, especially a simple tool, cost more than conventional tooling and should not be undertaken. Plastic tooling is almost always less expensive than other tooling if designs are complex. Material costs, as compared with metals, should take into account the actual number of tools which can be made with 100 lb. of material. When a plastic tool made of thermoplastics is scrapped, some of the material may be ground up and reused. The most expensive part of labor costs is the skilled work in preparing the molds. Experienced woodworkers are especially good at such work. If master parts are available, the expense of preparing a mold for a plastic tool to process such parts is far less expensive. Pouring is done with ordinary suitably trained labor. Over-all savings often run to one-half to two-thirds of the cost of conventional tooling while time saving may amount to 90% as compared with conventional tools.

Forming-by-Drawing.—A mass production process was developed at Anderson Aircraft, Inc., for producing compound curved surfaces in sheet metals, such as skin panels for airframes or parts for automobile bodies, etc. The parts produced by this new forming process are known as "Formdrawings." The forming takes place by controlled drawing actions applied to a moving sheet while it travels at selected speeds (Frohman Anderson, Aviation, vol. 41). Interchangeable and adjustable forming elements and curve-control cams universally adjustable to produce curvatures within wide limits are mounted on the machines, tabulated figures, interpolated where necessary, being used for the setting. A set of the elements and cams may be adjusted to form a new job while the forming machine is running another, then quickly interchanged for the set of elements on the machine when the run has been completed.

The sheets are shaped in one operation, producing smoother continuous surfaces which are not impaired by the process, eliminating a large per-

centage of joints, and cutting down scrap losses. Patterns, molds, dies, jigs, power hammers, wheelers, drop hammers, stamping and hydraulic presses, and heat-treating equipment are not required, the forming machine producing the results formerly secured on such equipment. Various panels can be arranged to be formed in a single large sheet by nesting in tandem, single or multiple rows, for the purpose of reducing scrap and saving labor and time. Formed sheets can be reprocessed by the method if changes in design have been made after production has been started. Capacities of machines have been up to a sheet width of 66 in. and a length of 30 ft. One to four panels per minute is the average rate of output. The process is applicable also to the formation of frame members and other parts.

Advantages brought about are:

1. Saving of material by ability to use entire surface of blank except an inch or two at the ends.
2. Ability to form preblanked sheets, making it possible to nest the blanks.
3. Ability to form sheets of unlimited dimensions, duplicate or dissimilar shapes being made in a single operation.
4. Tapering curved panels requiring a cone-section blank or other irregular trim lines can be nested and then formdrawn, saving considerable amounts of material.
5. Forming of large panels eliminates joint footage, saving excess metal —lap joints, reinforcing strips, trim-off scrap.
6. Tryout sheets on the process are reduced to three, sometimes one, and often none, the tryout sheet being reformed if adjustment is not correct on the initial try.
7. One-piece parts replace assemblies built by welding, the latter process sometimes warping the metal and necessitating a replacement.
8. Reduction of riveting or welding.
9. Expensive dies are eliminated, costly handling is avoided and die storage is replaced by a record card showing the set-up of the forming elements to produce a given shape.

Rubber Press.—The properties of rubber—elasticity, incompressibility, flow under pressure, resistance to cutting and pitting—make it usable in the form of pads or to serve as one part of a die for shearing, blanking, and forming operations. If it is retained in a metal ring, its flow will be restrained. Complex parts, not readily processed otherwise, can be produced. Shapes that otherwise would have to be built from riveted or welded parts can be made in one piece and deep drawing can be done to shape stronger parts with lighter weights. Quantity production with minimum and rapid tooling can be obtained at low cost, high speed, and with high accuracy by setting up a press to form several parts of the same or different kinds at one time. Production up to 50,000 pieces per day can be obtained, often by unskilled labor.

Sometimes a succession of rubber pads applied in dies and removed at successive strokes of the press, produce far stronger and better shaped parts than by having the forming done by immediate contact of the dies at all points with the work at the early strokes. Familiarity with such procedures is required of production men and methods engineers, who must cooperate with designing engineers to have the latter develop designs suitable for such loss-cost fabrication, and with tool engineers to give them data for the preparation of tooling for such purposes (Frey

and Kogut, Metal Forming by Flexible Tools).* This method is known throughout industry as the Guerin Process, since it was developed and patented by Henry E. Guerin, Plant Manager, Santa Monica plant of the Douglas Aircraft Co., Inc. It is the major forming process used by the aircraft industry.

Dies.—Blanking dies, for which ⅜ in. is the standard height of the cutting die, may be made of different kinds of material. They may be of boiler plate, zinc alloys, or have Masonite or Pregwood in the body and steel for the cutting edge. Forming dies may be of steel plate, zinc, aluminum, magnesium alloy, zinc alloy such as Kirksite, cast iron (for certain purposes), Pregwood, or cast resin plastics. Plastic fibre boards have been used but are not good on long runs and may fail under shear.

Kirksite dies are cast from pure zinc to which has been added a small percentage each of aluminum, copper, and magnesium. The presence of an appreciable amount of lead, which is difficult to eliminate, makes such dies brittle and hence should be avoided by diluting the melt with a large proportion of pure alloy. Such dies are hard and durable, cast easily because of low melting point, require little finishing, and can be melted and recast. Like plastic tools, they can be produced readily in the user's plant if sufficient work is involved to justify the investment in equipment and they have been widely adopted in large metal-forming industries.

Production of dies, templates, etc., on profiling machines of the Keller type is an important process of which full advantage should be taken in planning the tooling methods, especially of the metal-working plants.

* Courtesy "Metal Forming by Flexible Tools," Chris J. Frey and Stanley S. Kogut, Pitman Publishing Corp.

SECTION 14

MATERIALS HANDLING

CONTENTS

Pneumatic and Hydraulic Equipment

Cranes

Track Systems

Portable Equipment

Self-Propelled Equipment

Coordination of Handling with Production

Organized Materials Handling Systems

Operation and Maintenance of Equipment

Investigating Economies of Materials Handling Equipment

SECTION 14

MATERIALS HANDLING

DEFINITIONS.—For a proper consideration of materials handling problems and their solution it is necessary to have a clear understanding of the terms used. The following definitions explain fundamental terms:

Handling materials is picking up and putting down, moving in a horizontal or vertical plane, or both, by any means, materials or products of any kind in their raw, semi-finished, or completely finished condition.

Handling equipment refers to all mechanisms used in materials handling, together with auxiliary devices that may be required to make complete operating units.

Bulk material means any loose, powdery, granular, or lumpy substances, such as flour, wheat, coal, etc.

Package material includes boxes, cartons, crates, barrels, sacks, and also open containers with bulk or fabricated materials in them.

Units may be packages as above defined, or individual pieces or parts.

PROBLEM OF MOVING MATERIALS IN MANUFACTURING.—Few factories have made studies which bring to light the **tremendous total weight of materials handled daily in making the products** they turn out. Each part must be handled to and from each machine, or through each manufacturing operation, and must be transported from department to department during the course of manufacturing. When a summation is made of the total weight which this extensive handling and rehandling involves, and the weight of the manufacturing equipment which must be handled with the materials, some appreciation is gained of the vast importance of adopting the best means of materials handling. Actual case studies showed, for example, that in a pipe foundry 67 tons of materials were handled for each ton of pipe turned out, and in a plant making agricultural implements, 180 tons of materials were moved for every ton of finished product. A fair average for all industry would probably be at least a 50 to 1 ratio.

In almost any industrial process, the greater part of the indirect labor employed is engaged in handling materials. Over any reasonable period the percent of savings from eliminating indirect labor wherever possible will be relatively great compared with percent of savings in other costs such as for raw materials, direct labor, fixed charges, and variable charges other than for indirect labor. Hand labor is the most costly kind of labor to employ in all places where the volume of work or the weights to be handled offer opportunities to use materials handling equipment.

Clark estimates that manufacturers in the United States pay for moving materials within their plants 80% of what they pay for freight, express, and parcel post handling. Blyth states (Chem. & Met. Eng., vol. 26). "**Cost of most products is almost directly proportional to cost of handling materials** of their manufacture into work, through

manufacturing process, and out of work." It has been estimated that 22% of the cost of manufacturing, on the average, is due to the handling of materials (Alford, Principles of Industrial Management). As a rule, cost of actual vertical or horizontal translation of materials is small as compared with cost of loading, unloading, reloading, lifting, sorting, and interruption to production due to the operator leaving, slowing down, or shutting down his machine or production unit to handle materials. The obvious conclusions to be reached in seeking to reduce cost is that:

1. Handling must be eliminated wherever possible, and, where it is necessary, the work should be done by mechanical means, not by hand labor.
2. Handling routine must be made as nearly automatic as possible so that costs for this work are a minimum.

These objectives require the use of materials handling machinery and of automatic machinery in processes and in the moving of the product (Montgomery, Chem. & Met. Eng., vol. 26).

The **increased production obtained by an uninterrupted steady flow of materials** to and from workmen or production centers almost always justifies the application of materials handling equipment to a given situation. Much of the progress made toward the development of modern manufacturing methods, particularly in mass production, has been due to effective materials handling methods. In certain industries materials handling equipment is the backbone of the production facilities and in some instances entire manufacturing plants have been laid out around the equipment as the basis.

Investigations by competent authorities have led to the statement of certain **materials handling principles.** Along this line Coes states (Trans. A.S.M.E., MH-50-7):

> The public is slowly beginning to appreciate the fact that the cost of living is intimately related to the cost of production and distribution, and that one of the big factors in the cost of production and of distribution is the enormous toll due to handling, picking up and putting down, and rehandling the materials of agriculture and industry.

Merrill points out that

> Synchronized materials movement and grouping of production processes are important principles in the proper working out of transport science in production. Systems of conveying, properly applied, may enhance production 10%, 25%, or even 50%, with the same manpower and machine equipment. In travel of materials through the processing route it is worked on, on the average, less than one-third, often but one-sixth of the time. Work in process is often the graveyard of profits.

Briefly, the **objective in materials handling** is to transport materials from point to point, without retrogression, with a minimum of transfers, and deliver them to their appropriate workplaces or production centers in a manner to avoid congestion, delays, and unnecessary handling. It must always be borne in mind that handling does not add value to the product but does increase its cost. The principle formulated by Alford is that:

> **The greatest economy in progressing materials through a manufacturing plant is secured when the materials move a minimum distance in passing from operation to operation.**

Basic Principles of Materials Handling

GENERAL RULES FOR MATERIALS HANDLING.—The following summary of general rules for the handling of materials includes the ten principles formulated by Coes.

Eliminating Wasteful Methods

1. Economy in moving materials is secured by not handling. Perform only the really necessary handling operations and eliminate all unnecessary handling operations.
2. Combine operations whenever practicable to avoid handling or transportation from one to the next.
3. Utilize gravity wherever possible.
4. Wherever gravity will not suffice, handle materials with mechanical assistance to the widest extent practicable.
5. Always weigh the possibility of having workers go to materials or subassemblies instead of transporting the latter to the place of use.

Planning Layouts

6. Provide continuous or appropriate intermittent flow of materials.
7. Lay out definite routes of travel for all processing, coordinate the flow of all parts, subassemblies, and final assemblies, and reduce the lines of travel to the minimum, avoiding retrogression and rehandling wherever possible.
8. Lay out production machinery for least handling, and shortest transportations between operations and without retrograde movements of materials.
9. Always keep the over-all handling problem in mind and make every installation fit in with the program for the entire plant. Do not use a low-cost handling method at one stage, which will result in high handling cost later. The over-all handling cost is the controlling factor.

Applying Equipment

10. Before buying new equipment be sure the existing equipment is being used most effectively.
11. Select, in general, the simplest purchasable handling equipment applicable to the problem.
12. Install standard equipment, which has demonstrated its effectiveness, wherever possible. Use special equipment only under special circumstances.
13. Do not expect any one kind of materials handling equipment to be the most efficient for, nor even universally applicable to, all the materials handling work in a plant.
14. Provide for alternate methods in case of breakdown.

Reducing Costs

15. Buy equipment for over-all savings, not first cost. The investment must be justified by the returns over all fixed charges and operating costs.
16. Do all handling operations—manual as well as mechanical—at the lowest feasible cost.

Coordinating and Facilitating Operation

17. When two or more pieces of materials handling equipment are used, coordinate their operation.

18. When two or more persons are engaged as a unit in handling materials, synchronize their work so that they are all always occupied; avoid arrangements where some of them are required to wait for others to complete their part of the work.
19. In loading or unloading operations, handle material in unit loads whenever possible and in the largest unit or container practicable.
20. Avoid transfers from floor to container or vice versa, or from one container to another.
21. Avoid mixing of materials so as to keep sorting work down to a minimum.
22. When storing materials, make provision for stacking as high as the ceiling, if possible, to make the most effective use of floor space. Such stacking, however, must not cut off the free spread of water from overhead sprinkler systems, in case of fire.
23. Provide suitable running surfaces and clearances for self-propelled materials handling equipment.
24. Give consideration to packaging of raw materials and finished products for mechanized handling. Improper units can limit good handling practices.

Use and Upkeep

25. Provide instructions to train workers in the most effective use of materials handling equipment.
26. Remove all operating hazards in methods and equipment to prevent accidents in handling materials.
27. Plan and make effective an appropriate program for the maintenance of all materials handling equipment.

INSTALLATIONS IN NEW OR EXISTING PLANTS.—In a **new industrial plant,** materials handling is an important factor in determining:

1. Plant location, present and future.
2. Departmental layouts and sequence of operation.
3. Manufacturing equipment and layout.
4. Plant capacity.
5. Total time of the manufacturing cycle.
6. Type of production control system to install.
7. Manufacturing cost per unit of production.

Materials handling devices and equipment will frequently cost less, in many instances, by being made an integral part of the plant.

In an **existing plant,** proper selection and installation of adequate materials handling equipment will result in:

1. Better layout.
2. Increased output.
3. Cutting down manufacturing time, and thus reduce work in process and increase the rate of turnover of working capital.
4. Better planning, routing, scheduling, and dispatching of production to smooth out production flow.
5. Lower manufacturing costs.

ENGINEERING AND ECONOMIC FACTORS.—Analyses made by Hagemann, in connection with activities of the Materials Handling Division of the American Society of Mechanical Engineers, have developed certain engineering and economic factors which require attention in any kind of a materials handling installation.

An installation, to be successful from the standpoint of both efficiency and economy, must be planned along the following lines:

1. Correct plant layout. Layout must be good before handling equipment can be effectively applied. This factor includes the general location of different departments, sequence of operations within each department, placing of productive machinery, location of storerooms and storage places, and placing of handling equipment.
2. Correct kind of handling equipment. This factor covers selecting the type of equipment most suitable for each individual application. Adaptability, capacity, flexibility, initial cost, installation cost, repair cost, depreciation, obsolescence, and many other factors must be weighed.
3. Correct use of equipment. Instruction of foremen and workmen in methods of getting the best service from the apparatus is most essential. It should be provided for when the installation is planned.
4. Provision for adequate maintenance. If regular inspection, cleaning, oiling, adjusting, and repairing are not taken care of, the equipment cannot function to its maximum advantage, and costly breakdowns or failures are sure to result.
5. Provision for regular check-up on performance. If the management does not periodically inspect handling methods, or call for regular reports on their functioning, the best results seldom will be attained.
6. Plans for thorough restudy of methods at stated intervals. This factor is something more than mere maintenance or management check-up. It involves an engineering study to see if:
   a. The utmost return is being secured from the existing equipment and methods.
   b. Handling methods are correlated with production processes, storage systems, etc., or if changes in operations have made the original plans obsolete.
   c. Capacities of handling equipment are adequate for the service required.
   d. New methods of operation could be instituted that would do the work better.
   e. Different equipment or new devices could be substituted, with greater economy.

An important point in regard to handling of materials during process of manufacture arises in connection with moving assembly lines. J. M. Schumann, Director of Tooling, Santa Monica Plant, Douglas Aircraft Co., brings this out as follows:

Complicated assemblies that require a multitude of operations may be assembled on:

1. Fixed Position Assembly Lines
   a. On fixed position assembly lines, the assembly jigs are stationary and the personnel completes the entire assembly, or moves from one position to another, performing the same operations at each position.
   b. This method permits a flexible plant layout since tooling may be shifted easily to accommodate different rates of production or new floor arrangements.
2. The Continuous or Intermittent Moving Assembly Line
   a. This type of assembly line lacks the flexibility for plant layout but offers many advantages where continued high production of one assembly is possible.
   b. The worker has an obvious and definite time element in which to accomplish his job assignment.

c. Job specialization to the highest degree is possible since untrained personnel will learn the few operations assigned to each in the minimum time.
d. The continuous moving assembly line shows definite advantages over either the intermittent or fixed assembly line because laxity in supervision, requiring either slowing down or stopping the line, is immediately evident to higher management.
e. Parts control, handling, and storage are greatly simplified since a few of each item only are required at each line position.
f. At the Santa Monica Plant of the Douglas Aircraft Company, Inc., time reductions for one assembly of as much as 60% were traceable immediately to a change from fixed position to continuous moving assembly lines during a period when a high percentage of unskilled labor was being employed.

These considerations emphasize the importance of materials handling equipment in connection with moving assembly lines.

POINTS TO BE COVERED IN AN ENGINEERING SURVEY.—The points to be covered in the engineering survey to measure the possible economy of an installation would include the following factors (Hagemann):

1. **Factors of plant and operating methods**
   a. Are the present manufacturing or operating methods permanent or temporary?
   b. How long will the present buildings remain in service?
   c. Is the general plant layout the best for manufacturing and handling requirements?
   d. Is the sequence of operations that which gives greatest efficiency?
   e. What processes and departments must be tied together?
   f. If trucks or floor types of equipment are to be used, are aisles and passageways ample for conveniences in handling, speed, safety, and noninterference with production? Are the floors made of wear-resisting materials? Are they level and smooth? Will they withstand the loads?
   g. If overhead systems are contemplated, is the building structure strong enough to hold them and are clearances sufficient for their installation?

2. **Factors depending on the materials or parts handled**
   a. Kind or nature of materials or parts handled.
      (1) Bulk or units
      (2) Large or small
      (3) Heavy or light
      (4) Shape
      (5) Rough or fragile
   b. Handled separately or in containers.
   c. Quantities handled.
   d. Continuous or intermittent flow.
   e. Under processing while moving?
   f. Distances over which transported.

3. **Factors relating to the handling equipment**
   a. Kind or kinds suitable for the job.
   b. Capacity of equipment.
   c. Hours it will be in service daily.
   d. Size of equipment.

e. Space required for operation. (For trucks this factor covers aisles, passageways, elevator platform sizes, etc.)
f. Flexibility (according to loads, etc.).
g. Adaptability to other service.
h. Power requirements.
i. Ease of operation.
j. Speed of operation.
k. Durability.
l. Relationship to other handling equipment in use or contemplated.
m. Auxiliary equipment required or economical to install (loading platforms, etc.).

4. **Dollars and cents measures**
   a. Initial cost of equipment.
   b. Cost of installation, rearrangement of, and alterations to, present equipment, to buildings, etc.
   c. Cost of maintenance, repairs, supplies, etc.
   d. Cost of power.
   e. Rate of depreciation.
   f. Rate of obsolescence.
   g. Probable salvage value when finally discarded.
   h. Cost of labor to operate.
   i. Cost of any necessary auxiliary equipment (such as charging equipment for truck batteries, etc.).
   j. Taxes and insurance.
   k. Interest on investment.
   l. License fees (for trucks that may operate on highways).
   m. Rent of space (also garage rent for trucks).
   n. Cost of supervision.
   o. Savings that the equipment will bring about in direct labor cost (number of men released for other work, etc.).
   p. Savings in labor burden (supervision, etc.).
   q. Increased production brought about.
   r. Savings in fixed charges on equipment displaced.
   s. Unamortized value of equipment displaced.

In the selection of the materials handling equipment itself, the fundamental considerations are:

1. Design of the equipment or system: strength, rigidity, capacity, etc.
2. Method of installation, for operating control, ease of adjustment and repair, provisions for later changes or additions.
3. Methods of operation: under normal or abnormal conditions, heavy overloads or average capacity.
4. Application of power: electric, gasoline, steam, air, hydraulic; flexibility through variable-speed transmission.
5. Application of automatic control devices: safety stops, microlevelers on elevators, limit switches on cranes, selectors on gravity feed conveyors, automatic filling regulators on conveyors, use of electronic controls.
6. Maintenance and repair of equipment: systematic inspection, cleaning, adjustment, lubrication, and repair.
7. Standardization of equipment: advantages of duplicate apparatus for interchangeability of units, to have spares available, and to reduce repair parts inventory.

TESTS OF ADEQUACY AND EFFICIENCY.—Another authority has developed a check list by which to test the adequacy and efficiency of materials handling methods and equipment in a plant. This check list is given in Fig. 1.

1. Production

a. Are materials delivered from operation to operation without manual handling?
b. Are they placed directly in the machine?
c. If they must be hand fed, are they placed so that the machine operator need make no unnecessary motions?
d. Are materials always delivered as rapidly as they are used?
e. Is set-up time at an irreducible minimum? Are tools changed as rapidly as possible? Is material delivered in units large enough to get the longest possible runs per set-up?
f. Is the plant laid out primarily for "straight-line" sequence or for process efficiency? If the latter is preferable, would more flexible handling methods permit its adoption?
g. Has manual handling been eliminated from millwright work?
h. Is scrap disposed of without manual handling?

2. Receiving and Storage

a. Are incoming materials (other than bulk commodities) received in unit packages suitable for power handling?
b. Are they unloaded and delivered to the storeroom without manual handling?
c. Are they stored to the roof whenever desired, without manual handling?

3. Packing and Shipping

a. Are finished products packed in unit loads suitable for power handling?
b. Are they stored to the roof whenever desired, without manual handling?
c. Are they stowed in outgoing carriers without manual handling?

4. Costs

a. How many men are engaged in handling materials full time? Part time?
b. Is any skilled labor ever required to do ordinary handling work?
c. What proportion of the direct labor payroll is represented by handling?
d. What is the cost per ton-foot of handling materials between departments? Within each department?
e. What is the cost of defective material and spoiled work? What proportion arises from present handling methods?
f. What is the cost of lost time? What proportion arises from present handling methods?
g. What are the present compensation rates and to what extent can they be reduced by elimination of handling injuries?
h. What proportion of lost-time accidents are a result of manual handling?

5. Handling Systems

a. If handling has been mechanized, are the systems in use in each case best adapted for the work?
b. Have they been obsoleted and replaced as rapidly as a net gain in efficiency could thereby be obtained?
c. Have they been supplemented by all improved auxiliary equipment of effecting further net gains?
d. Has everything possible been done to assist suppliers to ship in unit packages suitable for power handling?
e. Have customers been informed that their shipments will be made in unit packages on request wherever practical?

FIG. 1. Materials Handling Check List

METHODS OF CLASSIFYING EQUIPMENT.—Materials handling equipment may be classified in a number of ways but many of the classifications are confusing. The five principal ways in which to make classification are by:

1. Classes of apparatus—such as cranes, hoists, conveyors, lift trucks, etc.
2. Nature of service performed—lifting, transporting, etc.
3. Nature of material handled—such as loose or bulk, pieces or parts, packages, bundles, boxes, barrels, etc.
4. Major fields of industry served, such as mining, manufacturing, transportation, construction, etc.
5. Relative mobility of equipment—fixed path, travel in limited area, travel over wide areas.

An example of the **classification by kinds of apparatus** is given by Koshkin (Modern Materials Handling) * from which the listing in Fig. 2 is taken. The classification is not fully according to classes, for it includes a group made up of materials handling systems in various kinds of industries, which is an example of item 4, above—major fields of industry served—but it approaches very closely to pure apparatus classification. The author applied a decimal system designation for facility of identification and reference.

Decimal Group	Kind of Apparatus	Decimal Group	Kind of Apparatus
0.00	Conveying and hoisting systems in general	5 00	Ground-track transportation
1.00	Cranes	6 00	Trackless transportation
2.00	Special and auxiliary hoisting devices and accessories	7.00	Coal- and ash-handling systems and devices
3.00	Elevators and conveyors	8 00	Materials handling systems in various industries
4.00	Overhead transportation over definite lines of travel	9.00	Special materials handling devices and accessories

Expansion of Group 6.00		Expansion of Group 8.00	
6.00	Trackless transportation in general	8.00	Adaptation and coordination of materials handling equipment
6 10	Trailers	8 10	Handling materials in the plant yard
6.20	Tractors, gasoline, industrial	8.20	Handling materials in multistory buildings
6.30	Tractors, storage battery, industrial	8.30	Materials handling in warehouses
6 40	Trucks, gasoline, industrial	8.40	Handling raw materials in the steel industry
6.50	Trucks, storage battery, industrial	8.50	Materials handling in the foundry
6.60	Trucks for special purpose	8 60	Sand and gravel washing plants
6.70	Trucks, hand	8 70	Stone and lime handling
6.80	Tiering machines or portable elevators	8.80	Materials handling in coal and ore mines
6.90	Platforms, pallets, skids, containers, and other accessories	8 91, 8.92, 8.93	Use of cranes, hoists, accessories, and special devices; Use of elevators and conveyors in various industries
		8.94, 8 95, 8.96	Use of carriers—overhead, rail, trackless

Fig. 2. Classification of Materials Handling Equipment by Kind of Apparatus

A classification by **nature of service performed** is given in Fig. 3. This grouping by types of service is accompanied by a tabulation of the main use of each kind of equipment listed.

N. W. Elmer uses a classification, shown in Fig. 4, which is a **combination of two classes—general nature of material handled and nature of service performed.** He made this grouping to avoid the common error appearing in most classified lists whereby each kind of equipment is usually credited with all its possible applications, which, while the claims may be true, does not represent good engineering practice because the equipment should not be used as first choice in many of the installa-

* John Wiley & Sons, Inc.

Type	Main Use
1. Lifting and Lowering Devices (vertical motion)	
a. Block and tackle	Local hoisting
b. Winches	
Hand	Cargo handling
Power	Cargo handling
c. Hoists (fixed)	
Chain	Local service in foundries, machine shops, woodworking shops, etc.
Air	
Electric	
d. Skip hoists	Coal and ash handling
e. Hoisting engines	Construction service
f. Elevators	
Hand	Multistory manufacturing plants, serving charging platforms in foundries, etc.
Belted	
Hydraulic	
Electric	
Special	
g. Cupola chargers	Foundries
2. Transporting Devices (mainly for horizontal motion)	
a. Wheelbarrows	Yard work
b. Hand Trucks	
Stevedore type	Shipping; freight service
Box type	Special service in manufacturing plants
Rack type	
Platform type	
c. Industrial railways and equipment (narrow gage)	Heavy handling
d. Tractors and trailers	
Electric	Mass movement of products
Gasoline	
e. Tructractors	Rapid and severe service in manufacturing plants
f. Railway equipment (standard gage)	Transportation service
g. Car pullers	Spotting freight cars
h. Aerial tramways	Long distance conveying
i. Skids for rolling pipe, etc.	Storage and shipping
j. Pipe lines	Fluids
k. Pumps	Fluids
3. Devices Which Both Lift, or Lower, and Transport (combined vertical and horizontal motion)*	
a. Chutes	Gravity handling
b. Hoists with trolleys running on overhead rails	
Chain	General service in manufacturing plants
Air	
Electric	
c. Lowerators	In conveyor systems
d. Lift trucks	
Hand	Rapid service on good floors or roadways in all types of manufacturing plants
Electric	
e. Small crane trucks	
Electric	Lifting and transporting fairly heavy loads
Gasoline	
f. Portable elevators or tiering machines	Stacking service in storerooms
g. Auto trucks	Heavy trucking inside or outside of plant

FIG. 3. Classification of Materials Handling

TYPE	MAIN USE
3. Devices Which Both Lift, or Lower, and Transport (combined vertical and horizontal motion)*—*Cont'd*	
h. Conveyors	
Apron	Bulk or package materials according to specific nature
Bar	
Barrel	
Belt	
Bucket	
Pivoted bucket	
Chain	Unit products
Disc scraper or flight	Bulk material
Drag scraper	
Package	Unit or package products
Portable	
Belt	Bulk materials
Bucket	
Roller	Unit parts or packages
Pneumatic	
Suction	Loose and light* materials
Pressure	
Roller type	
Gravity	Unit or package products
Power driven	
Screw	Loose materials
Slat	Unit products
Spiral	
Chute	Unit or package products
Roller	
Production line conveyors	
Assembly type (as in auto industry)	Machine assembly radio assembly, etc.
Sacking type (as in cement mills)	Cement packing, etc.
i. Tramrail systems	Handling units or assemblies in manufacturing plants
j. Cranes	
Jib	
Hand	Local service on heavy shop work
Electric	
Floor operated	
Hand	Limited travel on heavy shop work
Electric	
Cage operated	
Monorail	Long distance travel in shops and yards, loading vessels and cars, usually on heavy work
Bridge—overhead traveling	
Gantry	
Ore	
k. Locomotive cranes	Yard service in manufacturing plants, on construction, etc.
l. Car dumpers	Bulk shipments
m. Ramps	To give access to different levels
n. Trestles	For storage of materials

* Includes those devices usually traveling horizontally which pick up material; also those devices which usually provide for elevation during horizontal travel—such as ramps, trestles, etc.

Devices by Type of Service

tions where it possibly might fit but not operate nearly so efficiently as some other kind of equipment.

The preferred lists in Fig. 4 cover only the first choices for an economical installation of equipment from the standpoint of low original cost and low operating expense. If the equipment tabulated does not fit the particular problem, there is open for selection a wide field of other possibilities, such as air, steam, and hydraulic devices, and a number of special conveyors and special applications of standard types.

A classification by **major fields of industry served,** as already stated, is combined in the Koshkin grouping by classes of apparatus (see Fig. 2).

Service	Kind of Conveyor
Conveyors for Bulk Materials:	
Feeders and short horizontal conveying	Apron Screw Reciprocating Drag
Long horizontal conveying without spans between buildings	Belt
Where a tripper or bridge would be required for a belt	Redler Flight
Short inclined conveying	Flight Apron
Longer inclined conveying	Flight Belt Redler
Vertical conveying	Belt and bucket centrifugal) Redler V-bucket chain (slow speed)
Combined horizontal and vertical conveying	Redler
Conveyors for Packaged Materials:	
Horizontal conveying	Belt
Vertical conveying	Finger-type lift
Circuit conveying	Overhead tramrail (automobile plant type)
Downhill conveying	Gravity

Fig. 4. Classification of Equipment by Materials and Service

The fifth method mentioned above—**relative mobility of equipment**—is one of the simplest methods of approach. It lists the equipment under three main groups: equipment which is fixed so that it operates within the limits of its installation, equipment which can travel in a limited area, and equipment which is free to move anywhere. These main groups may be broken down by operating characteristics of the equipment, whether by gravity, mechanical or electrical power, or pneumatic or liquid flow (hydraulic). Each group then may be roughly subdivided according to classes of materials handled, such as unit or package, bulk semi-fluid, and equipment for handling more than one class of material. The tabulation in Fig. 5 is a development of this method of classification.

In the following pages, information is given as to operating characteristics and general applications of those types of materials handling equipment most commonly used in factories. (Applications, design data, and formulas of conveyor equipment throughout this section are largely from the Lamson Corporation. H. C. Keller, Engineering Manager, Application and Design of Package Conveyors, Trans. A.S.M.E., 1943.)

Gravity Equipment

CHUTES.—Chutes are the most economical means of lowering materials from one level to another. They are of simple construction and under ordinary operating conditions their maintenance cost is practically negligible. They are usually made of structural steel and sheet metal so shaped as to act as a confining means for lowering materials. The **straight chute** is used where the distance from upper to lower level is short.

Spiral Chutes.—Spiral chutes are used for long drops or in spaces where it is physically impossible to install a straight chute, or where delivery must be at a point vertically below the point from which the material comes. They are constructed with one to four spiral blades or troughs and are usually mounted about a center post. Both gravity and centrifugal force are utilized, packages being impelled downward by gravity and outward by centrifugal force, thus producing a retarding effect. Control of speed is obtained by varying the shape of the bed and the pitch. Straight or spiral inclines may also be constructed in the form of roller conveyors.

Capacity varies with the rate at which materials may be lowered, without damage, in a steady stream. While the chutes are capable of handling all classes of materials that will slide, their use is normally confined to lowering boxes, barrels, cases, crates, bundles, bales, and all types of packages or containers which do not require exceptional care. They should not be used for fragile loads, or where there is great variation in weight or where loads are more than 300 lb. Some chutes, however, have been designed to handle items weighing up to 2,000 lb. Also chutes should not be used where there is great variation in the humidity of the surrounding air, especially when sacks or cartons are being handled.

Keller states:

Under average conditions, straight chutes are declined at a 20° angle for cartons, 18° for wood boxes, and 15° to 17° for steel pans. On curved and spiral chutes the angle at the outer guard rail is the same as the angle of decline specified for straight chutes. The height of the side guards on straight chutes should be no less than one third the height of the highest load. On curved and spiral chutes, the outer guard rail should be somewhat higher than the greatest height of the load. The height of the guard is measured at right angles to the bed.

Gages of metal to use for chutes are given in Fig. 6 (Keller). Straight chutes made by bending up the side guards from the bedplate should be constructed according to the gage for the bedplate.

GRAVITY WHEEL CONVEYORS.—Gravity wheel conveyors consist of pressed-steel wheels mounted along the vertical sides of two structural steel angle frames which are welded with a gap between to

Class of Equipment	Type of Equipment	Class of Materials			Nature of Movements				
		Package	Bulk	Semi-Fluid	Hori-zontal	Up Incline	Down Incline	Elevat-ing	Lower-ing
A. Fixed Path									
1. Gravity Equipment	Chutes	x	x	x			x		x
	Wheel Conveyors	x					x		
	Roller Conveyors	x					x		x
2. Power Conveyors	Live-Roll Conveyors	x			x	x	x		
	Flat-Belt Conveyors	x	x		x	x	x		
	Troughed-Belt Conveyors		x	x	x	x	x		
	Slat Conveyors	x			x	x	x		
	Apron Conveyors	x	x		x	x	x		
	Wire-Mesh Conveyors	x	x		x	x	x		
	Drag-Chain Conveyors	x	x		x	x	x		
	Swivel-Chain Conveyors	x			x	x	x		
	Roller-Flight Conveyors	x			x				
	Cross-Bar Conveyors	x			x	x	x		
	Chain-Trolley Conveyors	x			x	x	x	x	x
	Arm Elevators	x				x	x	x	x
	Vertical Slat Elevators	x						x	x
	Suspended-Tray Elevators	x						x	x
	Reciprocating Elevators	x						x	x
	Industrial Elevators	x						x	x
	Flight or Scraper		x		x	x	x	x	x
	Redler Conveyors		x		x	x	x	x	x
	Screw Conveyors		x	x	x	x	x	x	
	Ribbon Conveyors			x	x				
	Bucket Elevators		x		x	x	x	x	x
	Skip Hoist		x			x		x	
	Drag Scraper		x		x	x	x		
	Tramways and Cableways	x			x	x	x		
3. Pneumatic and Hydraulic Equipment	Pneumatic Tube Systems	x			x	x	x	x	x
	Pneumatic Conveyors		x		x	x	x	x	x
	Hydraulic Conveyors		x	x	x	x	x	x	x

B. Limited Area									
1. Cranes	Jib	x			x	x	x	x	x
	Overhead Traveling	x	x		x	x	x	x	x
	Hand-Power Traveling	x			x	x	x	x	x
	Gantry	x	x		x	x	x	x	x
	Cantilever	x	x		x	x	x	x	x
2. Track Systems	Monorail Systems	x			x	x	x	x	x
	Industrial Railways	x	x		x	x	x		
	Locomotive	x	x		x	x	x	x	x
C. Wide Area (mobile equipment)									
1. Portable	Portable Conveyors (Most types under A-2)								
	Two-Wheel Hand Trucks	x			x	x	x		
	Four-Wheel Hand Trucks	x	x	x	x	x	x		
	Hand Lift Truck Skid System	x			x	x	x		
	Hand Lift Truck Pallet System	x			x	x	x		
	Wheeled Jack Live-Skid System	x			x	x	x		
2. Self-Propelled	Power Lift Truck Skid System	x			x	x	x		
	High-Lift Trucks	x			x	x	x	x	x
	Fork Truck: Pallet System	x			x	x	x	x	x
	Tractor-Trailer System	x			x	x	x	x	x

FIG. 5. Standard Types of Equipment Classified by Range of Service

Type of Load	Straight Chute		Curved Chute		Spiral Chute	
	Bed	Guard	Bed	Guard	Bed	Guard
Cartons or sacks	14	16	14	14	14	14
Wood boxes	14	14	14 to 12	14 to 12	12	12
Wirebound boxes, or steel pans	12	14	12	12	10	10

FIG. 6. Metal Gages for Chutes

provide the desired width. The wheels on each frame extend sufficiently above the frame to provide a rolling surface. A three-wheel type is available which consists of the above two-rail unit with a third row of wheels in the center mounted on a through shaft. This type of conveyor, where applicable, affords economical means of conveying, and is used to handle boxes, crates, bundles, and other packages having a solid and reasonably firm bottom.

GRAVITY ROLLER CONVEYORS.—Conveyors of the gravity roller type consist usually of two light angles or channels designed for maximum deflection of .33 in. in a 10-ft. span and cross-braced to form a frame. Between the sides are mounted a series of cylindrical rollers

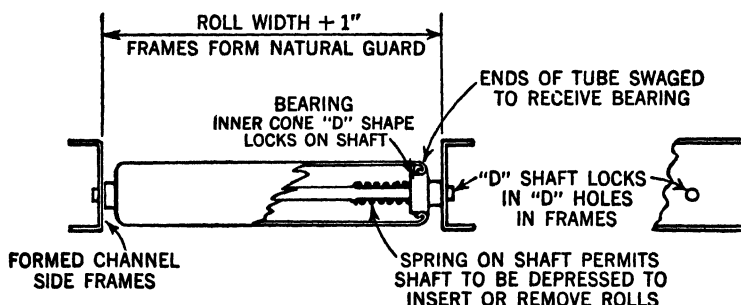



FIG. 7. Section Through Roller Conveyor

constructed of tubing (Figs. 7 and 8) and revolving on ball or other free-running bearings, grease-packed when operated under wet, dirty, or acid conditions. A double-roller type is also built, consisting of two side rails and a center rail, and carrying a double run of rollers. Shafts are locked in the side rails and the inner races of the bearings are locked on the shafts. The gage of the roller tubing (Fig. 8) is determined by the impact of the load, but is usually sufficient to make the rollers as strong as the bearings and shaft. The capacity of the rolls is not materially decreased as the length increases.

The spacing of the rollers is determined by the weight and length of the packages to be handled, the maximum spacing being one-third

Roll Diameter, in.	Load Capacity of Roll, lb.	Wall Thickness
1 to 2	50 to 200	18 gage to 12 gage
2⅛ to 2-9/16	150 to 1,000	16 gage to 7 gage
2¾ to 4	500 to 5,000	10 gage to ½ in.
Over 4	7,500	¾ in.

FIG. 8. Details and Capacities of Roller Conveyors

of the minimum package length, so that there are always three rollers under the load.

Loads must have a rigid riding surface. Preferably, they should also be constructed of the same materials and should be approximately of the same weight. When loads exceed 100 lb., investigations are necessary to make sure that damage will not result. Loads up to 40,000 lb. have been carried on roller conveyors but not by gravity. Fragile articles should not be moved by gravity.

Grades required for travel depend largely on the weight of the package to be conveyed, the nature of the riding surface, the number of rollers in contact with the package at any given time, and the kind of bearing installed. Experience indicates that heavy steel drums will move satisfactorily on a slope of 1/4 in. per ft., steel tote boxes or hardwood boxes of 15 to 75 lb. on 3/8 in. per ft., heavy cartons 1/2 in. per ft., while light cartons may require a slope of 1 1/2 in. or more to the foot. On hard-bottom loads and heavy cartons, the grade is reduced as the weight goes up, but cartons must not drape over rolls.

Gravity roller conveyors are made in various widths up to 30 in. or more, and in straight sections of standard lengths with alternate ends permitting quick and easy splicing of sections to any desired length. Lines can be placed permanently, or quickly run in any direction for special or temporary service.

Curves of two- or three-rail construction are obtainable as standard units for 45° and 90° turns, flat, or banked for either left or right turns (Fig. 9).

Frog units consist of two intersecting curves that deliver to a common line of conveyor. If the frog unit is used, it is necessary to have the packages traveling on each of the legs of the frog, timed so that there will be no interference at the junction point, or to use a mechanical interlock which will clear packages at the junction.

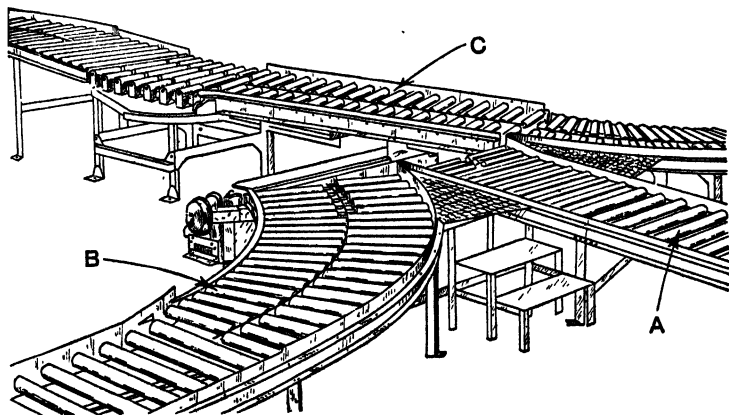



Fig. 9. Gravity Roller Conveyor Sections

Y-sections consisting of a straight section leading into another at an angle, usually 45°, are used to deliver packages from individual feeder lines to the main or pick-up line of the system. This section is most commonly used in shipping rooms where feeder lines act as temporary storage areas.

Two-way switch sections are used when it is necessary to change the routing of packages from one line to another. The switch is so designed as to permit the single line to receive from, or deliver to, either of the two lines (Fig. 9).

Ball turntables are often required to transfer packages from parallel lines to a line that lies at right angles. The table consists of a steel plate which carries large-diameter hardened steel balls running in a housing carrying a number of small balls.

Gravity Roller Spirals.—Gravity roller spirals are built the same as the gravity roller conveyor but are fabricated in spiral form. The gravity roller spiral offers an economical means of lowering packages which must be handled with exceptional care. Any package which will travel on a gravity roller conveyor can be lowered directly on the rollers, while use of pallets, trays, or tote boxes permits successful handling of small parts and irregular objects. This type of spiral may be used as a means for temporary storage since packages will start or come to rest easily and evenly on the roller runway. Thus, a full load of packages may be allowed to back up on the spiral, and as the lowest packages are removed, the load will automatically travel downward.

Gravity roller units may be used in any combination that the specific conditions may require, to make a complete handling system and may be hung from the ceiling or mounted on fixed or movable stands on the floor.

Power-Driven Conveyors—Fixed Systems

LIVE-ROLL CONVEYORS.—In many cases roller conveyor sections are power-driven. Sometimes flat belts or round belts are snubbed against the underside of the carrying rolls by means of snubbing rolls or sheaves between the carrying rolls (Fig. 10). The belt is driven, transmitting movements to the rollers which cause the packages to move forward. The flat-belt type is commonly used when the conveyor is straight, while the round-belt type is used when there are curves in the conveyor. With this type of conveyor the load can be moved up or down grades and can be stopped without undue friction. Complete roller

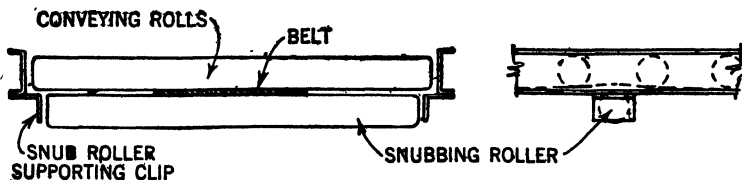



FIG. 10. Flat-Belt-Driven Live-Roll Conveyor

spirals can be powered with the round type of belt and in this way, under controlled continuous flow, loads of greatly varying weights can be lowered with less danger to light or fragile loads, especially where the latter are interspersed between heavier loads.

Roller-chain and sprocket drives are also used on the rollers. These drives are either single-strand, as in Fig. 11, or multistrand, as in Fig. 12. In some cases roller and shaft are integral and operate in ball bearings mounted on the side rails. In other cases, sprockets are welded to

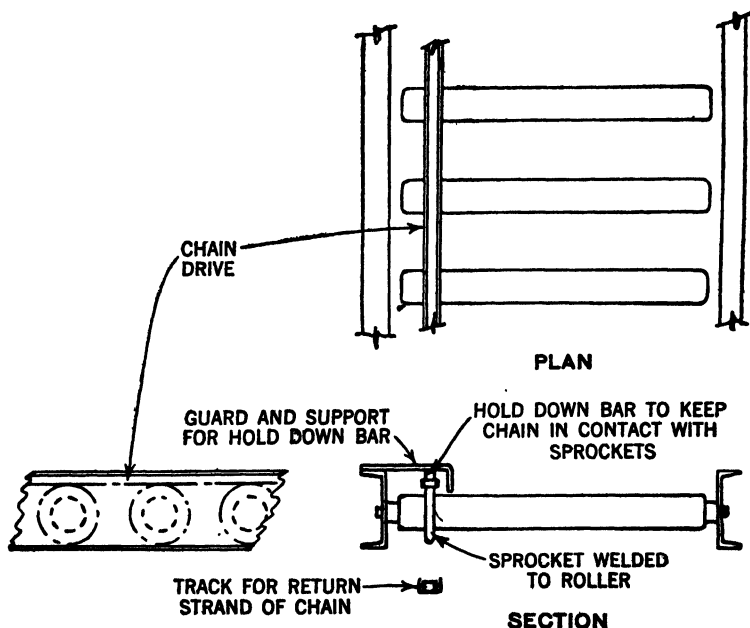



FIG. 11. Single-Strand, Chain-Driven Live-Roll Conveyor

the roller tubes, which have the usual ball bearings. Loads should have rigid riding surfaces, but need not be of uniform weight. Fragile loads should not be handled on conveyors where storage occurs, because of the danger of breakage due to blocking.

The horsepower requirements at the head shaft of a live-roll, belt-driven conveyor drive are calculated by the following formula:

$$\text{hp.} = \frac{(W + w) \times f \times S}{33{,}000}$$

where W = Weight of live load on conveyor, lb.
w = Weight of all rolls and belting, lb.
f = Friction given in Fig. 13.
S = Speed of conveyor, ft. per min.

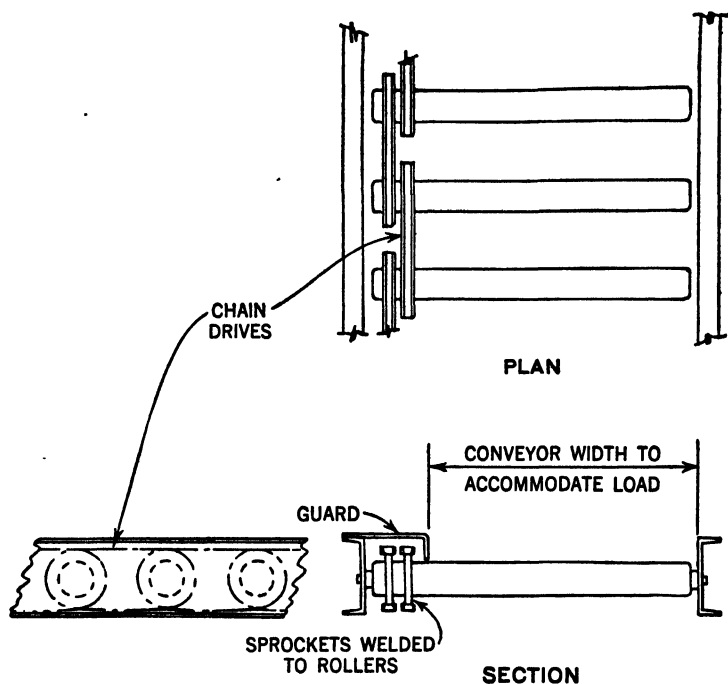



FIG. 12. Multiple-Strand, Chain-Driven Live-Roll Conveyor

In Fig. 13 the percentages are based on anti-friction bearings. In belt-driven conveyors, snubbing should be merely sufficient to propel the loads, but must increase as weights of loads increase. So two friction percentages for different weights are given in Fig. 13.

Type of Conveyor	Weight of Load, lb.	Friction, per cent
Belt driven	Up to 75	6
Belt driven	Over 75	10
Chain driven	Unlimited	5

FIG. 13. Percentage of Friction in Live-Roll Conveyors

The horsepower required for single straight-chain conveyors can be calculated from the formula given above by using w = weight of rolls, sprockets and chain. For multiple-chain conveyors the effective pull must be calculated progressively, using 98% efficiency for each chain drive.

FLAT-BELT CONVEYORS.—Belt conveyors ordinarily consist of roller conveyor sections on which an endless fabric belt, sometimes rubber covered, travels over the rolls serving as idlers, passes over end pulleys, and returns underneath, supported by idlers carrying the weight of the belt (Fig. 14). For light loads up to 50 lb. per sq. ft., a steel or wood trough may be substituted for the idlers.

Flat belts are used for **sorting,** light assembly work, and for handling certain bulk materials such as salt, sand, etc. The flat belt conveyor has only one-half the bulk-material capacity of the troughed belt described below.

The **adaptability of the belt conveyor and elevator to package handling** arises from its smooth, noiseless operation, the possibility of operation in either direction, and the ease with which packages may be diverted. It operates more efficiently at high speeds than any other continuous carrier. The continuous surface of the belt adapts the conveyor to packages of even the smallest size. In manufacturing plants where work in process is handled in trays or tote boxes, this conveyor may be used in two-way service, handling loaded boxes on the upper side and sending back empty containers on the return side of the belt.

Belt speeds range from 2 ft. to 200 ft. or more per min. under special conditions. The most common speed for general package handling is about 100 ft. per min.

Spacing of rolls is determined by length and weight of loads. For light loads 24-in. or even 36-in. centers are satisfactory. For heavier unit loads, the maximum roll spacing can be half the length of the shortest load. On the return side the maximum spacing is usually 10 ft.

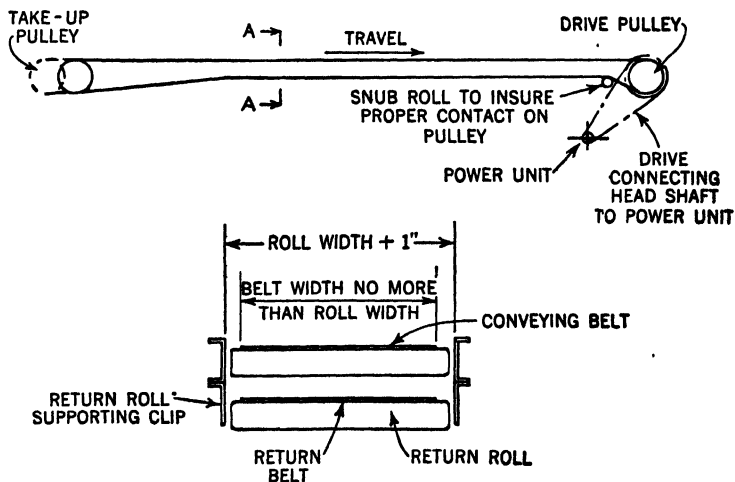



Fig. 14. Diagram of Belt Conveyor

The horsepower required at the head shaft of horizontal belt conveyors is

$$\text{hp.} = \frac{(W + w) \times f \times S}{33{,}000}$$

where W = Weight of live load on conveyor, lb.
w = Weight of rolls and belting, lb.
f = Friction given in Fig. 15.
S = Speed of conveyor, ft. per min.

Indoors, under constant normal humidity conditions, untreated cotton canvas belting can be used. Rubber-impregnated belts are installed where humidity varies greatly, while fully rubber-covered belts are required where the conveyor is exposed to the weather. Rubberized belting is not used when belts slide in troughs.

In calculating horsepower for elevating conveyor belts the conveying run must be calculated independently of the return run. The horsepower at the head shaft is

$$\text{hp.} = \frac{[.05r + L \sin\theta + fL \cos\theta + .05\, l \cos\theta - l \sin\theta]S}{33{,}000}$$

where r = Weight of all rollers, lb.
L = Weight of upper run of belting and live load, lb.
l = Weight of return run of belting, lb.
θ = Angle of incline, degrees.
f = Friction given in Fig. 15.
S = Speed of conveyor, ft. per min.

When the conveyor is used to lower loads the formula becomes

$$\text{hp.} = \frac{[.05r + l \sin\theta + fL \cos\theta + .05\, l \cos\theta - L \sin\theta]S}{33{,}000}$$

Type of Bed	Cotton or Untreated-Canvas Belting, per cent	Rubber-Impregnated Canvas Belting, per cent
Roller	3 to 5	3 to 5
Steel slider	20	21
Wood slider	22	30

Fig. 15. Percentage of Friction of Belting on Roller and Slider Beds

The lowering formula may give a minus value, which must be used as a plus value to find the strength needed in the drive gearing to hold back the conveyor from running away under the load.

The term within the brackets may be called "effective pull," and by its use factors such as total load on head shaft and stress in belting can be calculated. In Fig. 16, T_1 and T_2 are, respectively, the tensions in the tight and the slack sides of the belting at the head pulley under the most common conditions.

Maximum stress in belting = Effective pull × T_1
Maximum load on head shaft = Effective pull × T_1 + Effective pull × T_2

Take-up pulleys, with screw adjustment, are provided to compensate for stretch in the belting. Canvas belting requires an adjustment of 1% of the length of the conveyor, rubber belting about half that much. On long conveyors, and on short conveyors subject to temperature and humidity fluctuations, weighted take-up pulleys are used, the weight being calculated thus:

$$\text{Weight} = 2 \times \text{Effective pull} \times T_2$$

For conveyors which are sometimes reversed to run in the opposite direction

$$\text{Weight} = 2 \times \text{Effective pull} \times T_1$$

Amount of Wrap on Pulley, deg.	T_1	T_2
180	1.64	.638
200	1.54	.541
210	1.50	.500
220	1.46	.462
230	1.43	.428

Fig. 16. Tension in Belting at Head Pulley

Flat-belt conveyors are often installed to convey loads up or down inclines. The customary angle of inclination is 15° for miscellaneous materials, but this incline can be increased to 27° by using a rough-surface rubber belt. Cleats may be fastened to the belting to permit the handling of packages up a greater degree of incline if desired.

TROUGHED-BELT CONVEYORS.—The troughed-belt conveyors are similar to the flat-belt described above except that the belt runs on troughed idlers which form the belt into a concave shape. They are perhaps the most economical means of distributing or collecting bulk materials, because of their high capacity, low cost of operation, and simplicity of loading and discharge. This type belt has been constructed to handle materials economically for distances as great as nine miles.

Materials	Maximum Angle in Degrees above the Horizontal
Egg-shaped briquettes	10
Gravel (washed and screened)	12
Sand—wet concrete, grain	15
Crushed and screened coke	17
Run of mine coal, run of oven coke, gravel from bank, crushed stone	18
Bituminous slack coal, breeze coke, loose earth, crushed ore, damp sand	20
Wood chips (fresh)	28

Fig. 17. Maximum Angle of Inclination for Various Bulk Materials
(Adapted from Link Belt Co. data)

The belts may be equipped with as many loading hoppers as required and trippers to provide for complete discharge at desired points. Swiveling booms and shuttle conveyors may be used to distribute material over a wide area. They can be used for any kind of material which is not too wet or sticky and are used extensively for handling coal, coke, gravel, sand, slag, ore, and similar materials. The angle of inclination at which they may be operated varies with the characteristics of the materials (Fig. 17).

The maximum recommended belt speeds vary from 300 ft. per min. to 600 ft. per min. depending on the width of the belt and the character of the materials. Some materials such as grain can be handled as fast as 800 ft. per min.

The capacity of a given belt in tons per hour can be readily calculated by multiplying the appropriate factor given in Fig. 18 by the weight in lb. per cu. ft. of the material, and the result by the speed in ft. per min. The figures represent the tons per hour for each pound of weight per cu. ft. of material, for each ft. per min. of travel. For example, if lumpy sulphur weighing 80 lb. per cu. ft. is conveyed at the rate of 400 ft. per min. on a 24-in. belt, the capacity will be: the factor .01 × 80 × 400, or 320 tons per hr.

Width of belt .	14″	16″	18″	20″	24″	30″	36″	42″	48″	54″	60″
Tons per hr /lb./ft.	.0032	.0042	.0054	.0067	.0100	.0162	.0235	.0325	.0440	.0570	.0720

FIG. 18. Capacity Factors for Various Widths of Belts
(Adapted from Link Belt Co. data)

SLAT CONVEYORS.—The slat-type conveyor consists of slats of either steel or wood attached at their ends to two strands of chain, running in or on parallel steel tracks thus forming a continuous traveling platform (Figs. 19 and 20). The platform can be horizontal, inclined,

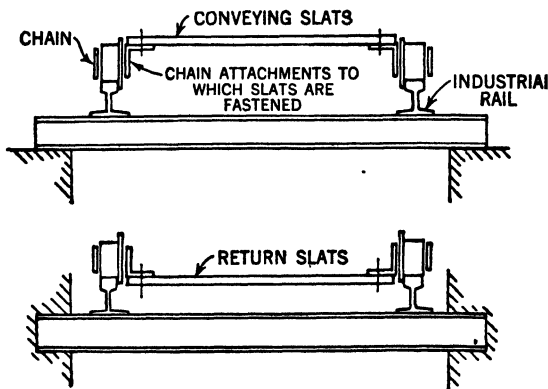



FIG. 19. Section Through Slat Conveyor with Flanged Rollers

or a combination of both. When equipped with blocks, cleats, or brackets to prevent materials from shifting, such a conveyor can be used on inclines up to 45° or more. It is normally used in cases where the load would damage the belting or lacks a surface suitable for live-roll conveyors—for example, conveying heavy objects or packages such as cartons, boxes, barrels, bales, etc., weighing as much as 500 lb. Slat conveyors are frequently installed flush with the floor to permit cross traffic.

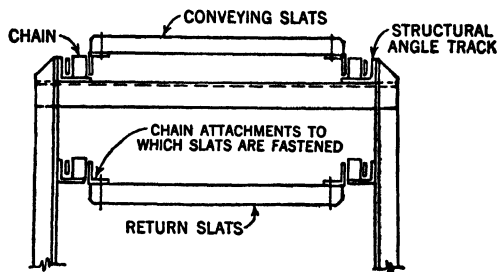



FIG. 20. Section Through Slat Conveyor with Straight Rollers

The width of the slats is about ½ in. less than the pitch of the chain. Wood slats are of commercial sizes, 2 x 4 in., 2 x 6 in., etc., dressed on all sides. Steel slats may be flat bars or steel shapes. Tracks are of angles or channels for plain rollers, and of standard rail sections for flanged rollers on heavy-duty conveyors.

Diameter of roller in chain	1½″	2″	2½″	3″
Friction, per cent.........	20	20	15	12

FIG. 21. Percentage Friction of Chains on Steel Tracks

The horsepower at the head shaft of a horizontal slat conveyor is

$$\text{hp.} = \frac{(W + w) \times f \times S}{33{,}000}$$

where W = Weight of live load on conveyor, lb.
w = Weight of chains and slats, lb.
f = Friction as given in Fig. 21.
S = Speed of conveyor, ft. per min.

The horsepower for inclined conveyors elevating loads is

$$\text{hp.} = \frac{[L \sin \theta + f(L + l) \cos \theta - l \sin \theta]S}{33{,}000}$$

where L = Weight of upper run of chains, slats and live load, lb.
l = Weight of return run of chains and slats, lb.
θ = Angle of incline, deg.
f = Friction given in Fig. 21.
S = Speed of conveyor, ft. per min.

and when loads are to be lowered

$$\text{hp.} = \frac{[l \sin \theta + f(L + l) \cos \theta - L \sin \theta]S}{33{,}000}$$

In the latter case, any minus value must be treated as a plus value as explained for belt conveyors.

Adjustments on slat conveyors to compensate for chain stretch are of the screw type, and the amount of adjustment is merely enough to allow a chain link to be removed.

APRON CONVEYORS.—The apron conveyor is a modification of the slat conveyor as "slats" overlap, forming a continuous moving bed (Fig. 22). Usually these slats are beaded along the edges to make a tightly jointed and leakproof continuous apron. The beaded effect retards the slippage of most bulk material when operated on inclines up to 25°. Cleats are bolted to the slats when operated at steeper inclines. These slats when provided with vertical ends will form an apron of overlapping pans, which is capable of handling small unit loads, and practically any loose bulky materials that are not of a sticky nature, such as coal, stone, ore, cullet, steel scrap, foundry refuse, etc. This type of conveyor is designed to withstand severe loading conditions and deliver a uniform flow. On the basis of handling 50 lb. per cu. ft. material, at 100 ft. per min., capacities of this type of equipment vary from 80 tons per hr. for an apron 18 in. wide to 290 tons per hr. for an apron 60 in. wide. Such conveyors are usually operated at speeds ranging from 60 to 100 ft. per min.; when used as picking or sorting-table conveyors, from 40 to 75 ft. per min.; as feeders, from 10 to 25 ft. per min.

FIG. 22. Details of Apron Conveyor

Horsepower calculations are the same as those for slat conveyors, with the weight of aprons substituted for slats in the formulas.

WIRE-MESH CONVEYORS.—The wire-mesh conveyor is similar to the apron conveyor except that the moving bed is formed by a continuous belt of wire mesh between two strands of continuous chains, instead of overlapping slats or pans. It is used largely in light-weight production on washing, draining, or other operations involving immersion of parts in, or their separation from, liquids.

DRAG-CHAIN CONVEYORS.—The simplest of the chain types is that consisting of a single strand of chain riding in a steel track and serving as a carrier for the object to be conveyed (Fig. 23). Usually the chain is provided with suitable projections or "pushers" at appropriate intervals to control the movement. This equipment is sometimes referred to as a drag-chain conveyor, and is designed to convey light, small, and uniform-size objects such as bottled beverages, bottled milk, pineapples, heavy steel drums, logs, etc., and is also used in pushing hand truck loads up ramps. Multiple-strand conveyors are likewise manufactured and used for loads which vary in size. With most loads the conveyors can turn 90° corners. At turns, the chain usually is guided in a steel track. Although wheels or rollers may be used here to reduce friction, such design is difficult.

Horsepower calculations are the same as for slat conveyors, with the substitution of the weight of chain only, in place of chain and slats, and the addition of 30% for sliding friction of chain on steel track. When there are turns, the effective pull of each section has to be figured progressively.

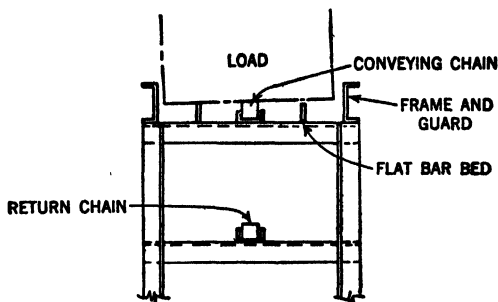



FIG. 23. Section Through Drag-Chain Conveyor

SWIVEL-CHAIN CONVEYORS.—Swivel-chain conveyors consist of two strands of synchronized chains moving in guides mounted on floor stands, to provide the means of transportation. They are used for conveying boxes, cartons, steel drums on ends, and other packages with firm bottoms. This type of equipment is capable of travel over practically any desired path. **Multiple-strand chain conveyors** of this type are used for special conditions in many fields, particularly in the steel industry where the temperature of the object is a factor.

PALLET-TYPE CONVEYOR.—Fixed pallets on a drag chain are used in foundries to move flasks from molding to pouring, shake out empty flasks, etc. Other varieties of pallet conveyors are used in assembly operations where the work is not suited to flat-belt conveyors, and pallets designed for holding specific parts carry them through progressive assembly operations. These conveyors are often intermittent in movement and operations are performed without removing the work from the pallet.

ROLLER-FLIGHT CONVEYORS.—Such conveyors consist of two strands of chain running in a track with a series of cylindrical rollers mounted between the chains at various centers so as to form a continuous traveling bed. This type can be used in **assembly lines** where it is necessary to stop materials in transit, and will not develop friction under the packages as the rollers turn only when the load is stopped. During transportation, the movement forward is produced by the chains, which are power-driven.

CROSS-BAR CONVEYORS.—Cross-bar conveyors consist of two strands of chain with cross-bars mounted between the chains at regular intervals and moving above a stationary bed so as to come in back of an object, such as a package or box, and push it horizontally or up an incline. Advantages of this type are simplicity of operation, low first

cost, and ease of automatic loading. This type of conveyor is also sometimes known as a booster or push-bar elevator and is used extensively to elevate in gravity conveyor systems to get set for the next section of gravity travel. It is used also for elevating or lowering packages from one floor to another and is suited for a fairly uniform range of

Fig. 24. Cross-Bar Conveyor

packages, or for practically any object of sufficient solidity and shape to slide on a runway at inclines of 30° to 60°. Capacities range from 500 to 1,200 packages per hr. at a chain speed of 60 to 90 ft. per min (See Fig. 24). Portable units of this type conveyor are used for piling bagged material.

CHAIN-TROLLEY CONVEYORS.—The chain-trolley conveyor is also known as the monorail chain conveyor, or overhead trolley conveyor. It consists of an endless-circuit overhead monorail track beneath

which moves an endless chain connected to trolleys at regular intervals. Two-wheel trolleys carry the load by means of hooks, racks, special carriers, etc., and the chain pulls them along. Line of travel may include 90° and 180° bends in the horizontal, and inclines up to 45° from the vertical, depending upon the spacing of trolleys and loads carried. Special installations have been made where the load is also carried vertically as well as horizontally. The most common application for this type of equipment is feeding from subassembly lines to assembly conveyors, or for carrying parts through spraying, plating, baking, painting, and other operations. It is widely used in the automobile and meat-packing industries. The conveyor dips when necessary to bring the load down to working height for removal at an operation, for performance of an operation while the load is on the conveyor, or for dipping parts in japanning tanks, etc., or it rises to cross an aisle, or to pass over some structure or piece of equipment in its normal path of travel.

Also, the conveyor acts as a storage medium because if an object is not removed it will recirculate over the system repeatedly until taken off at the point where it is needed. By utilizing the ceiling for transportation, floor space is saved and the vertical or inclined line of travel permits easy unloading at working height.

The 3-in. and 4-in. (I-beam size) chain conveyors are the most common. Horizontal turns are made by means of multiple-roller curves—useful because of low friction resistance and large radii—and by traction wheels. The latter method is best when the conveyor passes through temperatures of 400° or more because of its ample lubrication.

Drives are of the corner-sprocket or the caterpillar type. The former is used except where the corner radius is too large. Drives should be at the point of maximum pull and near a down curve, if any exists, to take chain slack away from the drive. The drives should never be in ovens or spray booths. Radii of vertical dips should be as large as practicable.

Take-ups, allowing removal of links from slack chains, are not necessary on long chains with several dips at one of which links may be taken out. They are necessary, however, on conveyors subject to high temperatures, in which case track expansion joints are required, using a coefficient of .0000065 per unit length per degree F.

Useful design data are given in Fig. 25 (Keller).

The formula for calculating the horsepower at the head shaft is

$$\text{hp.} = \frac{W \times f \times S}{33{,}000}$$

where W = Weight of chain, trolleys, cars, and live load, lb.
f = Friction, depending upon type of bearing in trolley
S = Speed of conveyor, ft. per min.

With long inclines in the conveyor there is considerable extra pull and the following horsepower formula must then be used:

$$\text{hp.} = \frac{(W \times f + L \sin \theta)S}{33{,}000}$$

where L = Live load on incline, lb.
θ = Angle of incline, deg.

	Size of System	
	3 in.	4 in.
Chain		
Pitch	3.031	4.031
Weight per foot, lb.	2.25	3.125
Ultimate strength, lb.	18,000	30,000
Allowable working load in lb. (level)	1,800	3,000
Allowable working load in lb. (dips)	1,000	2,000
Minimum amount of take-up, in.	7	9
Trolleys:		
Weight, lb.	3.5	7.5
Multiple of spacing, in.	6	8
Maximum spacing, in.	30	32
Maximum load, lb.	80 to 150	200 to 400
Average friction, ball bearings, per cent	2	2
Average friction, bronze bearings, per cent	3	3
Track:		
Size of I-beam, in.	3	4
Weight per foot, lb.	5.7	7.7
Vertical Bends:		
Trolley spacing, minimum radius	30 in.–10 ft.	32 in.–12 ft.
Trolley spacing, minimum radius	24 in.– 8 ft.	24 in.–10 ft.
Trolley spacing, minimum radius	18 in.– 6 ft.	16 in.– 8 ft.
Trolley spacing, minimum radius	12 in.– 5 ft.	–

FIG. 25. Design Data for Overhead Chain Conveyors

If the conveyor has more than four horizontal turns, it is necessary to calculate the pull on the chain progressively and to add 5% for friction loss at each turn.

ARM ELEVATORS.—Arm elevators are the simplest type of equipment for elevating or lowering packages at steep angles or vertically. They are usually constructed of two strands of continuous chains with projections or arms at intervals. When such elevators are equipped with finger-arm carriers or solid-tray arms, packages can be picked up automatically from loading fingers or stations on the upside and discharged over the top. When loaded on the down side, fragile packages can be safely lowered to any desired level. As gravity lowerers, controlled by small motors or mechanical brakes, these elevators have fairly wide application. Because of their flexibility, they find extensive use in multistory storage buildings and in industrial plants where space is important. They are also known as barrel and sack elevators. For bags, barrels, drums, or like objects, chain speed ranges from 40 to 60 ft. per min. For boxes, cartons, and bundles the speed ranges from 30 to 40 ft. per min.

VERTICAL SLAT AND VERTICAL BELT ELEVATORS.—Vertical slat elevators, also known as "Subveyors," consist of two continuous slat conveyor units set up face to face, vertically, at the de-

sired distance apart, with appropriate framework to keep them parallel. The slat surfaces of the units are equipped with cleats or steel angles which, when the speed of the elevators is synchronized, provide the means for picking up and lifting trays, pallets, or tote boxes of uniform size. This type of equipment may be designed to elevate to, or lower from, any floor level, and may be provided with horizontal belt or other conveying unit at upper or lower levels serving as automatic feeders or take-offs for the vertical equipment. These elevators are used particularly for elevating or lowering fragile parts or products on pallets or in containers.

Vertical belt elevators of similar design are sometimes employed for similar uses.

SUSPENDED-TRAY ELEVATORS.—The suspended-tray elevator, also known as the pivoted-tray elevator, consists of a series of pivoted suspended trays attached to two strands of endless chain running over top and bottom sprockets. Because trays or carriers are freely pivoted at points of attachment to the chain, the weight of the load, always centered well below these suspension points, holds the tray in a level position as it passes over the sprockets. Suspended-tray elevator-lowerers may be considered as belonging to two general classes—the simple swing-tray machine with solid or specially constructed trays, which are both loaded and unloaded wholly or partly by hand, and the highly developed automatic loading and discharging machine. In the latter, as the tray or carrier travels upward its projected fingers pick up the load, which has been momentarily resting on the loading arms, carry it over the top, and deliver it at the desired floor on the downside onto discharge fingers or stations which intercept the package as the carriers pass through. From these fingers the package slides, rolls, or is mechanically removed on rollers, belt conveyors, slat conveyors, drag chains, or other types of powered conveyors before the next carrier with its load reaches the discharge station. By having a system of pivoted loading and unloading stations, it is possible to use this type for both elevating and lowering. For bottles, cans, and high packages, the chain speed ranges from 30 to 70 ft. per min. Usually tray spacing is from 5 to 15 ft. With trays 5 ft. apart and speed at 50 ft. per min. the capacity of the elevator is 10 packages of average size per minute. On the fully automatic type the discharge station should be protected with limit switches, so that if a package does not clear the unloading fingers, the elevator will stop.

RECIPROCATING ELEVATORS.—Reciprocating elevators are those equipped with an electric hoist which raises or lowers a counterweighted car or platform operating along suitable guides, by means of a chain or cable over a sprocket or sheave. The construction is simpler than that of the continuous-elevator type such as the suspended-tray elevator, hence the cost is less. Such an elevator handles packages, cartons, barrels, boxes, pallets, or trays but is used where great capacity is not required. This type of reciprocating elevator lends itself to automatic loading and unloading and is normally used in connection with roller conveying equipment.

INDUSTRIAL ELEVATORS.—The term "industrial elevators" is most often applied to elevators operating in factories and other industrial buildings. In the factory they are usually called freight elevators. They are used not only in industrial buildings but also in all types of commercial structures, such as warehouses, railroad terminals, office buildings, hotels, apartment houses, hospitals, department stores, and garages. In addition, passenger elevators are often required in strictly industrial buildings for service to office areas. (Data herewith supplied by Elevator Manufacturers' Assn.)

Practically all elevators manufactured at the present time are of the electric type, the exceptions being short-rise hydraulic or hydroelectric plunger freight elevators and hydraulic elevators of other types for very special purposes.

Elevator developments have kept a step ahead of the requirements of the builders, so that any elevator equipment made necessary by increased heights of buildings or by special conditions can be readily supplied by the manufacturers. The elevator industry is continually developing its products so as to give building owners increased safety, uninterrupted service, and the minimum of maintenance and replacement of wearing parts. All modern elevators are provided with numerous safety devices to safeguard passengers and freight.

In all cases the characteristics of the elevators, either passenger or freight, are dependent on the requirements of the individual installation. This factor is particularly important in the case of freight elevators because of the wide variation in the weight and bulk of articles to be carried. Where factories produce and handle small articles of considerable weight, the inside dimensions of the elevator platform should be approximately 6 ft. by 6 ft., or larger. When larger articles are to be carried, the platforms may be 8 or 9 ft. in width by 10 to 20 ft. in depth.

In most buildings, **hand lift trucks, electric or gasoline lift-platform trucks, fork trucks, and industrial trucks with trailers** are used and in many cases must be carried from floor to floor on elevators. Because of the great variety and size of such trucks and trailers, it is necessary to obtain **detailed information on the equipment before platform dimensions can be determined.**

In terminal warehouses, the elevators often are arranged to carry loaded automobile trucks to any of the upper floors for loading and unloading. This method results in saving the extra handling that would otherwise be required at the sidewalk level and relieves congestion on the street. In such cases the elevator platforms would be around 16 to 18 ft. wide by 35 to 40 ft. in depth. These large elevators have capacities up to 40,000 lb. The majority of freight elevators have capacities ranging from 5,000 to 8,000 lb., but some are as low as 2,000 lb. and others are up to 10,000 lb.

Freight elevator car speeds vary with the height of the buildings and may range from 100 to 300 ft. per min. in industrial buildings and much faster in commercial buildings. In department stores, hotels, and other buildings where freight deliveries are important to efficient operation, speeds may be used up to 600 or 800 ft. per min.

While freight elevators formerly employed hand rope and other man-

ual devices for operation, present-day demands necessitate the elimination of unnecessary manpower, and automatic operation is almost universal. Car-switch operation is often used but does require an operator on the platform at all times. With double-button or collective control, the car may be operated by the person using the elevator.

Passenger elevator capacities, speeds, and platform sizes also vary with building needs. There is not such a wide difference between them except in the matter of speeds. In industrial buildings, a passenger elevator serving the offices would probably have a capacity of about 2,000 lb. at 150 to 350 ft. speed. In the higher office buildings and also those of the commercial type, the capacities would increase from 2,500 to 3,500 lb., with speeds of 500 to 800 ft. per min. and above.

Because of the special factors involved and the special nature of each installation, it is necessary to consult the engineering staffs of the elevator manufacturers for details and recommendations as to the type and character of elevator equipment best suited for each case.

Self-Leveling.—Almost all modern passenger elevators recently installed are of the self-leveling type, which insures the automatic leveling of the car platform with the floor level and the maintaining of that level under all conditions of loading and unloading. This feature is also widely supplied with freight elevators of the larger sizes. It is a most important improvement in this connection as it saves wear and tear on truck equipment due to uneven landings; it prevents damage to merchandise, reduces current consumption and saves wear on the elevator apparatus and on factory floors at the elevator approaches.

Traction-Type Electric Elevators.—The traction-type electric elevator, making use of the friction between grooved traction sheaves and hoisting cables, has proved far safer and more efficient than the drum-type elevator machine and is in general use. Traction elevators of the geared type have a worm and gear combination, and are used for car speeds up to 350 ft. per min. For higher speeds the elevator machines are of the gearless traction type with slow-speed motors, so as to eliminate the intermediate gearing and thus permit faster car speeds and provide greater efficiency. Gearless machines provide car speeds up to 1,200 ft. per min. for intensive passenger service in tall buildings.

All elevator manufacturers have standard combinations of load and speed which have been determined from their experience as being most suitable for many conditions. Almost any building requirement can be met with one of these established types.

Door Equipment.—Manual and power door and gate operation for both elevator platforms and for hoistway doors are available to suit any requirement for either passenger or freight service. Electric operation of such doors is now generally in use, thus saving much roundtrip time, especially for the passenger elevators. Freight elevators are generally equipped with vertical bi-parting doors at the floor level and the majority of these are power-operated. Safety gates are essential on automatic elevators.

The following information as to operating time for doors and for loading and unloading is of value:

DOOR OPERATING TIME

1. Average time for power-operated vertical bi-parting door, opening and closing (assuming door operation synchronized with micro-operation, which is typical) .... 7.0 sec.
2. Average time for hand-operated vertical bi-parting door, opening and closing. (This includes an average allowance for operator to walk from car switch to position for operating door) .... 22.0 sec.
3.* Average time for a folding car gate, opening and closing..... 3.0 sec.

* Freight car may or may not have a gate depending on local regulations. If used for combined passenger and freight service, a car gate generally is required. Automobile lifts usually do not have a car gate.

LOADING AND UNLOADING TIME
(Including Operation of Doors)

1. Average time for an automobile truck to run onto, or off, an elevator .... 15.0 sec.
2. Average time to run 4 hand trucks onto, or off, an elevator.... 40.0 sec.
3. Average time to run 4 trailer trucks (groups of 2 coupled together and pulled by 2 separate engines) onto, or off, an elevator .... 30.0 sec.

The use of electric transporters is often a means of saving time by keeping the factory mobile equipment off elevators.

ELEVATOR CARE AND MAINTENANCE.—Like all good machinery, elevators must be properly maintained to keep them at their inherent high level of performance, prevent interruption of service, and minimize repairs and replacements. Good maintenance requires periodic examination by competent mechanics. Most elevator manufacturers have facilities to take care of these requirements.

APPROACHES TO ELEVATORS.—Elevators are usually installed at points where truck traffic going from floor to floor can be most conveniently handled and distances of travel from the elevator to points where material is picked up or delivered are shortest. Often, therefore, elevators are near the middle of buildings, and frequently along outer walls and near building entrances in cases where the traffic is between buildings or from yard to building. It is necessary to provide ample aisles and approaches so that truck operation is facilitated, congestion of aisles is avoided, clearances are ample to prevent accidents, and trucks can move freely in and out without delay and maneuvering.

FLIGHT OR SCRAPER CONVEYORS.—The flight conveyor is one of the oldest and most dependable types of equipment employed in transferring materials horizontally or at an incline, up or down, and is especially desirable where the inclination is between 20° and 45° with the horizontal, and too steep for use of apron or belt conveyors. The flights are plates or special shapes which are attached to a single strand, or double strands, of chain. They push the material along in a steel trough for discharge at the end, or at desired intermediate points through gates provided at intervals.

Single-strand flight conveyors handle coal or other substances containing lumps up to about 5 in. The flights may slide on the bottom of

the trough or be carried by lugs or rollers attached to the chain or to the flights, supported on suitable tracks or guides (Fig. 26).

Double-strand flight conveyors are of similar construction except that two strands of chains are used and are usually attached to the ends of the flights. The spacing of the flights varies with the size of lumps, capacity, and inclination of the conveyor.

These conveyors are most commonly used to handle coal. Their capacities vary with size and type of equipment—from 30 to 110 tons of coal per hour for the single-strand, and 110 to 360 tons per hour for the

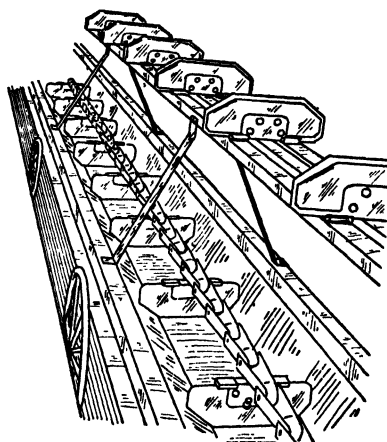



Fig. 26. Single-Strand Flight Conveyor

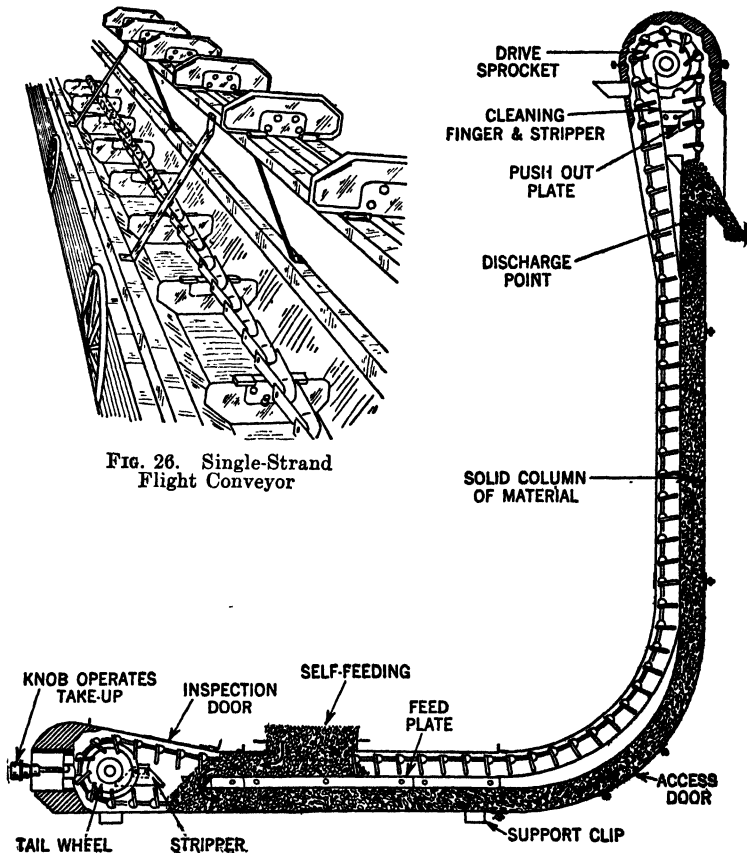



Fig. 27. Redler Conveyor

double-strand type. Since the material is pushed along in steel troughs, the conveyors should not be used for handling abrasive substances.

For low capacities up to 5 tons per hour, a single strand of large-size chain, without flights, is sometimes used to push the material along slowly in a trough of wear-resisting material. This type is suitable for ashes, cement clinkers, and other abrasive substances.

Redler, or flight "en masse," conveyors of the fully enclosed type are designed to handle practically any pulverized, granular, small lump, or flaky materials, horizontally, vertically, on inclines, or around curves. This conveyor employs the principle of moving materials en masse by a series of skeleton-type links or flights which become buried in the material within an entirely enclosed and dust-tight housing. This conveyor has some particular advantages over others of the flight type in that it requires less space and is capable of moving materials in any direction (Fig. 27).

SCREW CONVEYORS.—Screw conveyors consist of a solid or hollow shaft on which is wound a spiral blade or flight, rotation of which causes materials to be pushed horizontally along in a trough or on a bed of the material itself. They can be made in various lengths, diameters, and pitches. Screw conveyors are available in standard sectional lengths of from 5 to 12 ft. and diameters of from 4 to 24 in., depending on whether they are of steel or cast iron. Some are made of corrosion- or heat-resisting material such as bronze, monel metal, or other alloys, to meet the particular operating conditions. For abrasive materials like sand, ashes, and certain ores, chilled cast-iron screws and trough are used. Where materials are fragile or smooth, and slow movement of them is desired, double or even triple flights are used. Fig. 28 shows the capacities of the various sizes of horizontal screw conveyors for handling bulk materials at maximum recommended speeds and appropriate percentage of cross section in the material.

Pitch of the spiral may vary according to requirements, but in standard sections the pitch is approximately equal to the diameter. Screw conveyors are available with a variable pitched flight and cut or folded flights. The former type is used largely as a feeder and avoids overloading the conveyor portion, while the latter is used in conveying and mixing cereals, grains, and other light materials.

Some screw conveyors are designed to operate in a vertical position with maximum lifts up to 50 ft. and capacities as high as 50 to 60 tons per hour in handling bulk carbon black or similar substances.

RIBBON CONVEYORS.—Ribbon conveyors, which consist of a steel spiral ribbon instead of the full-width blade, are used for conveying or mixing wet, semi-liquid, or sticky materials.

BUCKET ELEVATORS.—Bucket elevators are made up of metal buckets mounted on, and carried by, one or two strands of chain or belt, all enclosed in a steel casing. This type of elevator will handle practically any bulk material.

In the **centrifugal discharge type** the buckets are loaded either by flowing the material into them, or by having them scoop it up under the foot-wheel. They then elevate the material and discharge it by centrifugal force as they pass over the headwheel. Speeds range from 200 ft. per min. for the small sizes when used on light, fluffy, or pulverized

Physical Characteristics of Material	Weight, lb. per cu. ft.	Percentage Cross Section in Materials	Cu. Ft. per Hr. for Various Diameter Screw Conveyors								
			4″	6″	9″	10″	12″	14″	16″	18″	20″
Free-flowing nonabrasive, flour, powdered coal, flaxseed, etc.	30 to 40	45	100	370	1,200	1,600	2,600	4,000	5,600	7,600	10,000
Fine, granular, nonabrasive grain, fine coal, hydrated lime, etc.	40 to 50	38	58	215	690	440	1,560	2,400	3,400	4,500	6,000
Fine, semi-abrasive, granular with small lumps; sized coal, coarse salt, etc.	40 to 75	31	37	140	450	620	1,050	1,560	2,250	3,100	4,100
Abrasive or semi-abrasive; cement, shale gypsum, etc.	50 to 100	25	.....	90	290	400	660	1,000	1,450	1,980	2,650
Highly abrasive, corrosive, or stringy; coke, quartz, silica, etc.	....	12½	...	20	66	91	155	240	350	480	630

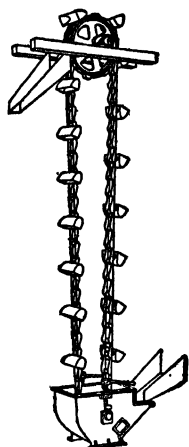
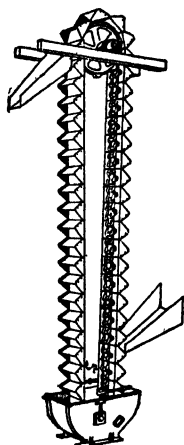
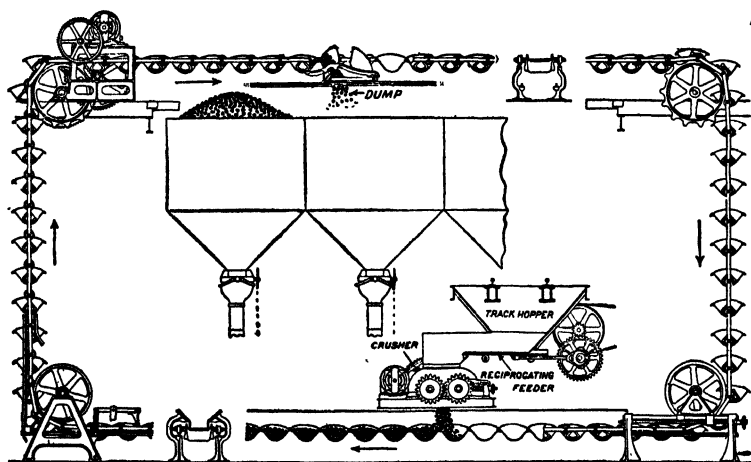
FIG. 28. Capacity of Horizontal Screw Conveyors
(Adapted from Link Belt Co. data)

A—Single Strand Centrifugal Discharge Elevator

B—Single Strand Continuous

C—Pivoted Bucket

FIG. 29. Types of Bucket Elevators

materials, to 800 ft. per min. for larger elevators handling grains or cereals at a rate of more than 3,000 bushels per hour. Heights rarely exceed 100 ft. and conveyors are usually installed as nearly vertical as practical to prevent chain and buckets sagging or swaying (Fig. 29).

Continuous-bucket elevators are made of a continuous line of triangular buckets. Discharge at the head is accomplished by using the back of each bucket as a chute for material from the bucket behind. The single-chain type is usually operated at 125 ft. per min. and although it has a greater number of buckets, its capacity is about three-fourths of the centrifugal discharge type. However, double-chain types with large buckets are available, with capacity for handling 100-lb. per cu. ft. material at 500 tons per hour, or three times that of the centrifugal discharge type. The load is received by means of a chute which discharges directly into buckets (Fig. 29). Continuous-bucket elevators are also available without casings, permitting them to be operated at angles up to 20° from the vertical. This inclined type is used normally for sand, gravel or stone.

Pivoted bucket elevator conveyors consist of a continuous line of buckets pivotally suspended between two long-pitch roller chains, which are supported on tracks. These conveyors can be made to follow a rectangular or any other desired path. They are slow-speed, usually operated at between 40 and 60 ft. per min., and can be loaded or discharged at one or more points (Fig. 29).

SKIP HOISTS.—A skip hoist consists of a large steel bucket equipped with flanged wheels, running on vertical or inclined guides of steel channels or T-rail tracks. The bucket is loaded manually or automatically, hoisted up to a discharge position over a storage bin or silo by winch and cable, and automatically dumped. The skip hoist is a unit complete in itself for receiving, elevating, and discharging batches of materials, usually abrasive, corrosive, or containing large, sharp lumps, or when exceptionally high lift is needed. It is used largely for handling coal or ashes and capacities vary up to 250 tons of coal per hour. Size of buckets varies up to 150 cu. ft. and height of lifts ranges up to 160 ft.

DRAG SCRAPER.—This equipment is sometimes called a drag-line conveyor or power hoe and consists of a large pusher or steel bucket operated to and fro over a pile of material by means of an engine and a system of wire rope and sheaves supported on posts or other forms of anchorage located at appropriate points around the pile. It is used to store and reclaim bulk materials, particularly coal, at capacities of 50 to 100 tons per hour.

TRAMWAYS AND CABLEWAYS.—A cableway consists of a span of cable suspended between two terminals or towers, serving as a runner for a load-bearing trolley. A tramway is substantially the same design as the suspension cableway but generally of much greater length, requiring supporting trestles at intermediate points. This type of equipment is used to transport materials such as coal, ore, sand, gravel, or cement that may readily be carried in buckets, or it may be used for handling logs, lumber, or other materials with the aid of suitable holding devices. It is also possible to carry at same time on one line several kinds of materials, such as ore, logs, and timbers.

When the distance between two terminal stations is very great—exceeding 1 to 1½ miles—or grades are very severe, an **intermediate tension station** is installed. At this point the track cables are parted, one end being attached to a fixed anchorage and the other end to a tension gear, similar to that used at the terminal stations. This prevents the excessive stresses developed in a cable of great length. A section of overhead rail is used with this arrangement to connect the track cable ends.

Pneumatic and Hydraulic Equipment

PNEUMATIC TUBE SYSTEMS.—These systems consist of cylindrical or oval-shaped carriers propelled in a tube or corresponding shape by compressed air or vacuum. They provide mechanical messenger service in industrial, commercial, and public organizations for the silent and swift transportation, in carriers, of drawings, documents, small packages, and individual units. In process industries they are used effectively in dispatching samples to laboratories, and returning the analysis to the factory without loss of time. In industrial plants it has been found economical to use this means of conveying on small parts between toolroom or storeroom and machines.

Indicating carriers are frequently used so that messages, or articles, being sent from any one station to any other station in a system may be transferred at the central desk without opening and examining the contents of carriers. For example, a message being sent from Station Number 5, destined for Station Number 12, is placed in a carrier and the indicating rings on carrier are set at Number 12. When this carrier arrives at the central desk, the attendant there merely transfers this carrier to the tube line going to Station Number 12. The indicating mechanism consists of a series of numbers engraved on the carrier body over which a ring (or rings) is placed with sight holes. By revolving the ring (or rings), the number (or numbers) desired may be registered through the sight holes. With this arrangement, it is possible to have complete intercommunication between all stations by simply running connecting tubes from each station to the central desk.

In some systems, automatic separation of carriers is desirable and this can be accomplished with either mechanical separators or magnetic separators.

Mechanical separation is accomplished by using different designs of the head of the carrier. A simple illustration would be two different types of carriers—one with a solid head and another with a recessed head. As the carriers enter the separator, those with the solid heads actuate a trigger, and the carriers are discharged at that point. Those carriers with the recessed heads do not actuate the trigger, and automatically continue on their way to discharge at a point further along the line.

Magnetic separation is usually accomplished by using steel and nonferrous carriers.

Some systems are provided with **automatic vacuum control** which cuts down the air flow on any line when no carriers are on it, and automatically throws the full supply into the circuit the instant a carrier is dispatched. The size of traveling containers or individual carriers de-

pends upon the size of the objects to be handled. The small carriers are just large enough to take a few bank checks when rolled and are about 1 in. in diameter and about 3 in. long. Large carriers such as those used to transmit mail are about 7 in. in diameter and 22 in. long and will accommodate 10 lb. of mail. The New York City mail-tube system, consisting of 27 miles of double tubes, handles about ten million pieces of first-class mail daily using carriers large enough to hold 500 average-sized letters.

PNEUMATIC CONVEYORS.—One variety of these conveyors is designed to handle bulk materials by suction produced by an exhauster or fan which partly exhausts air from an enclosed tank to which the conveyor pipes are attached. As air is sucked out of the tank, a current of air, which has sufficient velocity to float materials to be conveyed, is produced through the pipe line.

Conveyor pipes are provided with self-feeding nozzles, usually on the end of a hose. These are moved around in the material to be conveyed

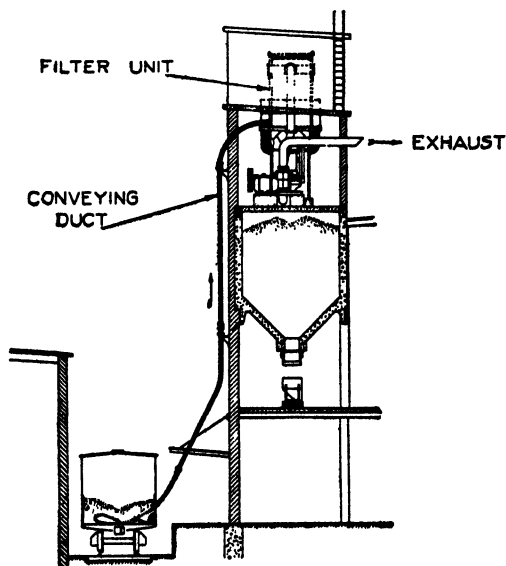



Fig. 30. Pneumatic Conveyor (airveyor)

and suck it up into the conveyor pipes through which it passes to the suction tank, where, under reduced pressure in larger area, it drops into the storage space. From here it may fall by gravity to storage points, or be handled with other devices, or feed direct to process equipment. (See Fig. 30.)

This type of pneumatic conveyor is particularly adapted for handling, from freight cars or ships, fine bulk materials such as grain, malt, seeds,

salt, beans, and other granular substances which are not sticky or fragile. Some ship-unloading units of this type handle 5,000 bushels of grain an hour.

Blower or pressure systems employ essentially the same principle of conveying except that movement of materials is produced by air pressure instead of suction and the discharge is into a filter container instead of a vacuum tank. This type is designed to handle powdery or crushed materials which tend to pack, such as lime, silica, woodflour, and soda-ash.

Pneumatic pump systems are used for handling highly pulverized materials such as cement, clay, and starch through pipe lines of considerable lengths. The materials are mixed with air as they are introduced into the system and become fluid enough to be forced through the system by mechanical pressure.

HYDRAULIC CONVEYING.—Many plants have occasion to make considerable use of hydraulic conveying in closed piping systems. Often such equipment is tied in so immediately with processing as not to seem to be materials handling, a term more commonly applied to what may be called "open" systems where operating attention is usually required to feed and remove or make use of the conveyed materials, consisting of package or bulk items. Service pumps for water and other liquids or materials, however, are performing automatically a materials handling service and should be recognized as part of the plant's handling equipment. Under large-scale operations where materials are put through in a fluid state, such as pulp in a paper mill, the connection is more obvious.

Hydraulic systems to handle materials carried in the water have been installed for phosphate rock, sand, coal, rock, and slurry, etc., besides ashes, sludge, and wastes. Tables have been compiled for calculating the capacity of such systems. Volume depends on velocity of flow, friction in the pipe, and the specific gravity of the materials carried. Data on these factors have been presented in various tables. Fig. 31 gives the gallons per minute required to deliver 100 tons of dry rock in 24 hours, the gallons varying with the specific gravity of the material itself and the percent of it by weight in the solution. The tables permit ready calculation of the amount of water and horsepower required to transport any material at any required rate through any required distance and against any necessary head.

Combined Pneumatic and Hydraulic Handling.—Combinations of pneumatic and hydraulic handling systems are highly effective where it is desired to collect dry materials and carry them to some point where they can be picked up by the hydraulic element for removal. Systems of this kind have been used to save labor and power in connection with the removal of refuse from both stoker-fired and pulverized-fuel-fired steam generating units (Allen-Sherman-Hoff Co.). This equipment also includes intermittent slag-tap and continuous slag-tap units.

The pneumatic portion of the system is so designed as to automatically load itself by means of the carrying air stream. No mechanical loading devices are required.

The material drops from the collecting hoppers into a "Windswept" dust valve. The air stream in passing through this valve picks up the

Specific Gravity of Rock in Solution	Percent Rock by Weight in Solution													
	75	70	65	60	55	50	45	40	35	30	25	20	15	10
2.5	12 236	13.965	15 694	17.955	21 945	23 408	27.132	31 787	38 038	45.752	56 924	73 682	101.622	157 472
2.6	11 970	13 699	15 428	17 689	21 679	23 142	26 866	31 654	37 772	45 486	56 658	73 416	101 371	157 206
2.7	11.704	13 433	15 162	17.423	21 413	22 876	26 600	31 388	37 506	45 220	56 392	73 150	101.120	156 940
2.8	11 571	13.167	15 029	17.157	21 280	22 743	26 467	31.122	37 240	44.954	56.259	72 884	100 902	156 807
2.9	11 305	13 034	14 896	17 024	21 014	22 477	26 201	30 989	37 107	44 821	55 993	72 751	100 701	156 674
3.0	11.172	12 768	14 763	16 758	20 881	22 344	26 068	30 723	36 841	44 555	55 727	72 618	100 500	156 408
3.1	10.906	12 635	14 497	16.625	20 615	22 211	25 802	30 590	36 708	44 422	55.594	72 352	100.316	156 142
3.2	10 773	12 502	14.231	16.492	20,482	21 945	25 669	30 324	36 575	44.289	55 461	72 219	100 148	156 009
3.3	10 640	12 369	14 098	16 359	20 349	21 812	25 536	30 191	36 442	44 023	55 328	72 086	99 998	155 876
3.5	10 368	11 959	13 802	15 963	18 492	21 540	25 259	29 916	35 875	43 885	55 041	71 791	99 703	155 541
4.0	9 705	11 357	13.199	15 360	17 889	20 938	24 256	29 313	35 292	43.282	54 438	71 188	99 110	154 938
4.5	9 296	10 888	12.730	14 891	17 420	20 469	24 187	28 844	34 823	42 813	53 969	70 719	98 641	154 469
5.0	8 928	10 519	12 362	14 522	17 052	20 100	23 819	28 475	34 455	42 444	53 600	70 350	98 272	154 100

Formula: $\text{U.S.G.P.M.} = T \times .1675 \left(\frac{W}{R} + \frac{1}{SpGr}\right)$

T = Tons of dry rock delivered by solution in 24 hours.
SpGr = Specific Gravity of the dry rock.
W = % by Wt. of water in the solution.
R = % by Wt. of dry rock in the solution.

FIG. 31. Number of U. S. Gallons per Minute Required to Deliver 100 Tons (2,000 lb. per ton) of Dry Rock in 24 Hours
(Allen-Sherman-Hoff Co.)

maximum amount of dust which the stream can transport. This means of loading the air stream insures that the system can never be clogged by overloading, hence results in handling material at a higher rate than is possible where mechanical loading is adopted.

Each dust hopper is equipped with a "Windswept" dust valve, these valves being connected in multiple, not series, to the transport system. Thus when the system is in operation, the particular hopper with its attendant valve at the moment being unloaded, receives the concentrated energy of the conveying air stream. This hopper is totally unloaded, after which the next valve and hopper are similarly unloaded, and so on through the entire system.

The dust is transported to a cyclone collector which is arranged for continuous discharge into a large storage bin from which point it is loaded to trucks or railroad cars by means of a rotary dust- and water-mixing device which produces a mixture neither dusty nor sloppy, suitable for transport to permanent fill.

In those instances where there are fill facilities within a reasonable distance of the plant, the cyclone collector, bin, and mixing units are omitted and the dust is discharged directly through a water ejector vacuum-producing unit called a "Hydrovactor" to a de-aerating tank located at an elevation which will permit gravity flow of the de-aerated solution to the point of discharge at the fill.

In other instances the Hydrovactor is arranged to discharge the material directly into an ash-pump sump, from which point it is pumped to the ultimate point of disposal.

In the absence of any permanent or temporary fill facilities the material is discharged to overhead dehydrating hydrobins where it is dewatered and made ready for commercially dry loading into railroad cars or trucks.

As an alternate to disposing of the material in an overhead dehydrating hydrobin, the material can be discharged to grab-bucket sumps.

The Hydrovactor unit uses as operating medium water at 100 lb. pressure, requiring 660 g.p.m. With water furnished in this volume and at the specified pressure, a 4-in. transport pipe system will handle approximately 15 tons of material an hour. By the use of two Hydrovactors in multiple and a 6-in. line, the system will handle 30 tons of dust per hour.

Pumps.—The Hydroseal pump (Allen-Sherman-Hoff Co.) is particularly designed to handle abrasive and corrosive solutions. These pumps are available over a wide range of capacity and head and are applicable for many purposes. Some units are completely protected with "Maximix" rubber to safeguard against attack from abrasive slurries. In service where material is of a size making it inadvisable to use a completely rubber-protected unit, a hard alloy casting is utilized for shells and impellers.

Both the metal pumps and the rubber-protected Hydroseal pumps incorporate sealing features which totally eliminate wear which normally takes place between the impeller and suction side. The advantage resulting may be explained as follows:

The conventional unprotected pump when new will start at very good efficiency but, because of the abrasive material leaking through the

clearance between the impeller and suction side plate, this efficiency rapidly decreases and within a few weeks, on an average, the conventional sand pump will show an efficiency varying between 30% to 40% as compared with its initial efficiency of 60% to 65%. This loss in efficiency shows up in a fixed length of pipe line in reduced capacity of discharge. As this capacity lowers, the velocity of the solution in the pipe lines lowers until finally the solution is moved so slowly that the solids drop out and the line becomes clogged. To provide against this contingency, it is common practice to overspeed the conventional pump considerably at first so that when its efficiency does drop off there will for some time be sufficient velocity to prevent clogging. Manifestly this results in the necessity of having to equip the pump with a very much larger motor than would be required should its efficiency be maintained throughout its life.

As the Hydroseal pump prevents leakage between impeller and suction side plate, its efficiency is maintained throughout its life, and as a result not only is there a saving of large amounts of power but also it is practical to drive the pump with a much smaller motor.

In addition to reducing continually the pumping efficiency, abrasion in conventional unprotected sand and slurry pumps frequently causes annual maintenance costs to exceed the initial cost of the pump. In certain services where a pump is handling a highly abrasive solution an iron impeller will last only a week or less. Where the rubber-protected Hydroseal pump is applicable, this excessive wear can be avoided and service life can be measured by months instead of weeks.

Also, Packless pumps are available for use in connection with chemical solutions (Allen-Sherman-Hoff Co.). Because of the difficulties caused by packing and stuffing boxes when ordinary centrifugal pumps are used to pump corrosive acid solutions, this pump has been designed without a stuffing box, hence the name Packless. All parts of the pump which come in contact with the acid being pumped are protected against corrosion by means of natural or synthetic rubber. The Packless pump does not require any sealing solution.

PIPING FOR ABRASIVE MATERIALS.—In the handling of abrasive or corrosive materials pneumatically or hydraulically, it is necessary that the piping, and often the operating equipment, be designed to resist wear and chemical action.

Rubber Conduit.—One variety of such piping—Diversipipe (Goodyear Tire & Rubber Co.)—is wire-reinforced, wrapped fabric, black-stock conduit with integral flanges on each end to keep the material being conducted free from contact with metal. This pipe is recommended for use in the conducting of corrosive chemicals or abrasive materials such as sand, gravel, cement, salt, ashes, pulverized slag, and other materials. It is applicable where pipe lines are subject to electrolysis corrosion, water hammer vibration, or where the flexibility of rubber hose is necessary to make installation easy. Advantages of its use are light weight, flexibility, reduced maintenance and uniform inside diameter, constant capacity because of nonadherence of sludge, resistance to crushing or kinking, and noncollapsing under suction. It comes in lengths up to 50 ft.

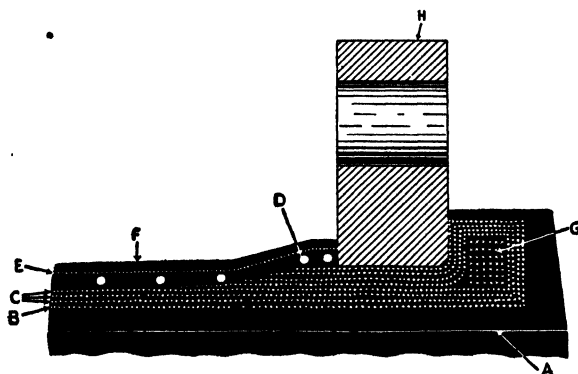
The beaded-end type (Fig. 32) is installed where pressure does not

A—Tube, gage ¼"; extremely high tensile, abrasion-resisting black stock; carried over flange face to act as gasket for sealing flange connection
B—Breaker; single-ply, heavily coated open-mesh fabric
C—Fabric reinforcement; multiple plies of fabric frictioned with rubber
D—Wire reinforcement; helix to add bursting resistance, prevent collapse under suction, resist against crushing or kinking
E—Fabric reinforcement; single-ply, same as C
F—Cover; medium gage, abrasive, sun and weather-resisting
G—Beaded flange; layers of wire built over plies C which are folded back under D and H
H—Retaining ring; metal, drilled with standard bolt-hole circle, and backing up flange G

FIG. 32. Abrasive-Resisting Rubber Conduit—Beaded End (Diversipipe)
(Goodyear Tire & Rubber Co.)

Size	Plies Exclusive Breaker "B"	Working Pressure, lb./sq. in.	Approximate Weight, lb.	
			Hose Only per Foot	Metal Retaining Rings, Pair (See Note)
2	3	75	3.0	6.9
2½	3	75	3.6	11
3	3	75	4.2	13
4	3	75	5.3	24
5	3	75	6.4	26
6	4	75	7.9	30
8	5	75	11.7	49
10	6	75	16	65
12	7	75	20	98

NOTE: This includes all material in beaded flanged end plus metal rings. To find the weight of a given length, multiply the hose weight per foot by the length and then add the retaining weight per pair.
All sizes recommended for suction service.
Standard 150-lb. drilling for bolt hole circle. Special drilling can be furnished provided that the bolt hole circle is not smaller than the 150-lb. standard drilling.

FIG. 33. Data on Beaded-End Rubber Conduit (Diversipipe)

A—Tube, gage ¼"; carried over flange face to act as gasket
B—Breaker
C—Fabric reinforcement
D—Wire reinforcement
E—Fabric reinforcement, same as C
F—Cover
G—Full-face flange; the cover, fabric reinforcing plies C and E, end reinforcing plies J, and tube extend to extreme diameter of retaining ring H. Holes drilled through rubber flange and lined with rubber to protect fabric.
H—Retaining ring; metal, standard bolt-hole circle, backing up flange for rigid bolting
J—End reinforcing; cord fabric providing extra end-pull resistance for rubber flange and relieving stresses at base of ring H

FIG. 34. Abrasive-Resisting Rubber Conduit—Full-Face Flanged-End (Diversipipe)
(Goodyear Tire & Rubber Co.)

Size	No. of Plies Exclusive Breaker "B"		Maximum Working Pressure, lb./sq. in.	Approximate Weight, lb.	
	Body	Ends		Hose Only per Foot	Flanged End, Pair (See Note)
4	5	8	150	6.0	23
4	8	13	250	7.4	37
6	6	10	150	8.8	30
6	11	19	250	12.6	54
8	8	13	150	13.3	48
10	10	16	150	17.4	68
12	12	20	150	23	98
14	14	24	150	29	117

NOTE: This includes all material in rubber flange, plus end-reinforcing plies, plus metal retaining ring. To find the weight of a given length, multiply the hose weight per foot by the length, and then add the flanged-end pair weight.
A 150-lb. working pressure hose furnished with 150-lb. drilling for bolt hole circle, and 250-lb. working pressure hose furnished with 300-lb. drilling for bolt hole circle. Special drilling can be furnished provided that the bolt hole circle is not smaller than that of the standards listed. Wall thickness does not permit any exceptions to be made on the bolt hole circle dimensions.
Solid metal rings furnished on all sizes.

FIG. 35. Data on Full-Face Flanged-End Rubber Conduit (Diversipipe)

exceed 75 lb. per sq. in., or where suction is used. Multiple layers of special wire are built over tube and fabric reinforcement plies (C in figure) after which the plies are folded over the wire and extended back into the hose under the metal retaining ring and wire reinforcement. The sizes, plies, and weights of this type are given in Fig. 33.

In the full-face flange type (Fig. 34) the cover, fabric reinforcing plies (C and E in figure), end reinforcing plies J, and tube are extended to the extreme diameter of the retaining ring. Holes are drilled through the rubber flange and the holes lined with rubber to protect the fabric. The multiple plies J protect additional end pull resistance for the rubber flanges and relieve otherwise localized stresses at the base of the retaining ring. Data on this type are given in Fig. 35.

Metal Alloy Piping.—Metal piping consisting of alloys to harden the metal against abrasive action are used in many installations. Such piping comes in the usual sizes and with alloy fittings, but is expensive so that its main applications are made in industries where large volumes are handled and usually for shorter distances.

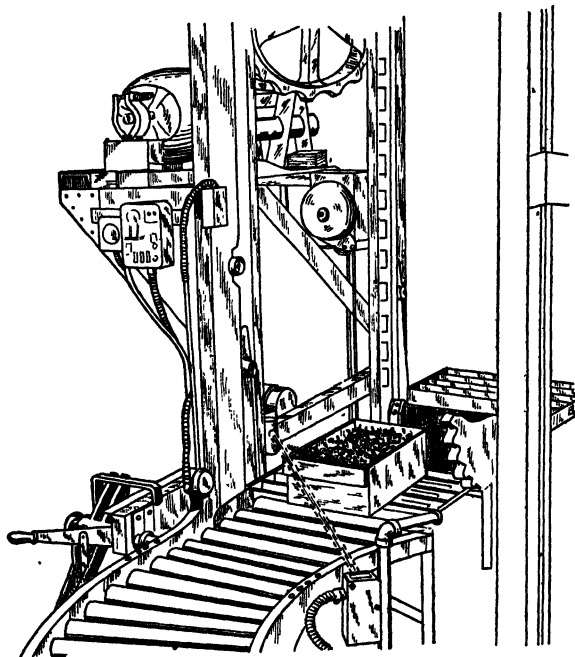



FIG. 36. Photoelectric Control Utilized to Stop Vertical Lift When Tote Box Intercepts Beam
(General Electric Co.)

ELECTRONIC CONTROLS FOR MATERIALS HANDLING EQUIPMENT.—The development of electronic tubes for industrial applications has resulted in the use of electronic controls for materials handling operations. Fig. 36 shows a photoelectric control utilized to stop a vertical lift when a tote box on a roller conveyor intercepts the light beam. The object is to prevent piling up of boxes. In this installation the light beam is placed at an angle to take care of all size boxes.

In Fig. 37 are illustrated a photoelectric relay and light sources on a pre-selective conveyor dispatching system. By means of signals on the

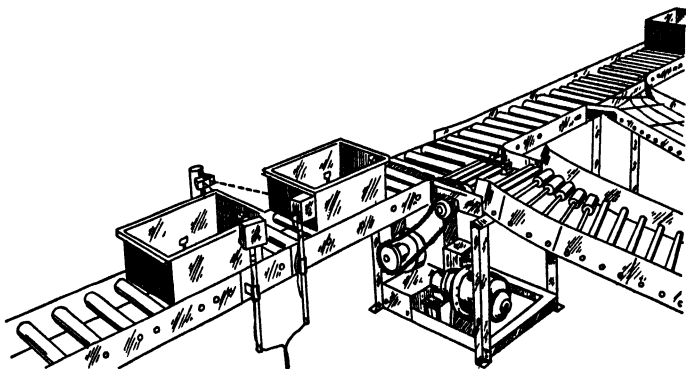



FIG. 37. Photoelectric Relay and Light Sources on Pre-selective Conveyor Dispatching System
(Logan Conveyor and General Electric Companies)

boxes the latter are sent down the desired lead-off conveyor. The use of a photoelectric relay for counting valves leaving a heat-treating furnace is shown in Fig. 38. This relay will count, control, and limit operations.

Photoelectric relays are also substituted for limit switches on larries which distribute coal to sectional hoppers feeding chain grate boilers. As the larry oscillates slowly back and forth on an overhead track in front of the hopper, hinged vertical uprights in the center of the track between the rails intercept the light beam from the photoelectric relays, which are mounted at each end of the larry, as it reaches the limit of travel in the forward and reverse direction. An electronic time-delay relay permits the larry to stop when it requires refilling. One of the uprights in certain installations is let down out of the way to allow the larry to run to the coal bin, where a similar upright intercepts the light beam, thus stopping the larry.

A company handling coal built a car dumper installation in which a loaded car is fastened mechanically to the rails, rolled over to dump, righted, and rolled off by gravity. Formerly, when an empty would be delayed in running off, it would be turned over on the floor. A photoelectric relay and light source were then installed on opposite sides of the track at the run-off end. The empty now blacks out the beam from

the light source and thus prevents the dumper from operating until the car has rolled off (Hanna Coal Co.).

Six large doors at the entrances to the receiving and shipping departments of Brown & Williamson Tobacco Co. are opened and closed under the control of photoelectric installations, which replaced manual methods. When incoming or outgoing shipments approach any of the

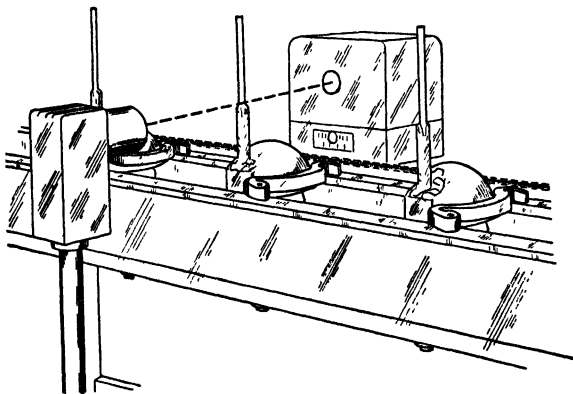



FIG. 38. Photoelectric Relay Used for Counting Valves on a Conveyor System
(General Electric Co.)

doors they cut off light beams focused on phototubes and the door opens automatically and closes after the load has passed beyond the light source. A limit switch at the top of the door on a hinged panel prevents persons from being caught in the door. The switch operates the control and reverses the door. Besides door opening cost, the cost of heating the departments was reduced because of the reduction of time during which the doors were open. Savings were estimated at $30 per day. The same idea can be applied to opening and closing factory doors between buildings.

Cranes

JIB CRANES.—Jib cranes are the simplest forms of cranes and consist of a straight-bar or I-beam horizontal jib carrying a trolley and hoist and supported by a rotating mast or column pivoted at top and bottom in pivot blocks or bearings. When mounted on wall or post, the crane is pivoted on brackets. The manner in which the jib is supported varies with the conditions under which it is to operate. When headroom is a controlling factor, a **bottom-braced type** is used in which the supports are placed below the jib. When such is not the case, the **top-braced type** with supports between the top pivot and the jib is preferable, because it leaves the space underneath clear within its entire area

and permits the load to be handled with equal facility at the end of the jib or close to the column.

For outdoor work a **top-and-back-braced type** of jib crane is used in which the jib extends some distance back of the column or mast and serves as a strut for truss-rods extending from the top of the column to the base. The column or mast is supported by guides or stiff-legs in a manner similar to that employed in derrick construction. When possible, guides or stiff-legs should be installed so that the jib may swing in a complete circle.

Many jib cranes of this type are equipped only with ordinary trolley and hoists, as in other smaller types of bottom-braced and top-braced jib cranes. They are generally used for handling lumber, logs, and similar materials.

Capacities of jib cranes vary largely with the radius and anchorage. The cranes are seldom used for loads exceeding 10 tons.

OVERHEAD TRAVELING CRANES.—There are two main varieties of overhead traveling cranes—hand-powered and electric-powered. In both cases the cranes have a bridge, or structural member, mounted on wheel-trucks. This bridge runs on parallel overhead rails carried on the columns of buildings or on structural uprights. Across this bridge there runs a trolley on small wheels, running on tracks or on the flanges of an I-beam and carrying a hoist which operates a winch and cable for lifting and lowering. To a hook on the cable, or on the fall block if there are two or more vertical strands to the cable for lifting heavy loads, can be attached a sling, or tongs, or cables or chains from the corner of a box or "skip," for handling units or packages. Special attachments enable the cranes to handle bulk or ferrous materials.

Such cranes can serve the entire rectangular area between the rows of columns or supports carrying the overhead track. They are used for all kinds of handling, indoors and outdoors, in industrial plants. In some cases, as in cupola charging, the trolley and hoist unit can move off the bridge to a track leading to a point outside the normal area served. Many of these cranes may be controlled by electric cord control from the car, eliminating the necessity for a crane operator who sits idle when the crane is not in use.

The bridge may consist of a single girder for light cranes to six-girder I-beam or latticed-section structures for very heavy work. The bridge may be hand-operated or motor-driven, trolleys may be hand-operated or motor-operated, hoists may be of the differential chain, air-driven, or motor-driven type.

Hand-powered overhead traveling cranes are the simplest of the overhead traveling-bridge cranes. They are of the single-girder or two-girder type, and are used most frequently for light or occasional service where high-speed operation is not needed. The bridge is either chain-operated or merely pulled along by the hoisting cable or the load. The trolley is usually propelled across the bridge by hand chain, or sometimes merely by pulling it along by the hoisting cable or the load. The hoist is usually a chain block or chain-operated hoist, but sometimes an air hoist is installed. The flexible air line, however, often is inconvenient and may leak, so that air hoists are not widely used. In some cases, the bridge is wired and the hoist is motor-driven.

Power-driven overhead traveling cranes have motor-drives for the bridge, and usually also for the trolley and hoist. The simpler one-girder variety, however, may have chain-operated trolleys and chain-operated or air-driven hoists. The all-electric-motor cranes are by far the most numerous and range up to 400 tons or more in capacity, depending on the nature of the industry and service in which they are used. The 5-ton to 30-ton sizes are most common. In power-driven cranes, the bridge speed may vary from 25 to 40 ft. per min. where care and accuracy of operation are required, up to 400 ft. or more per min. where speed is essential. Trolley and hoist speeds are slower. The movement of the trolley across the bridge of the crane is known in shop parlance as "racking in" if toward either end of its track, and "racking out" when toward the center of the bridge.

GANTRY CRANES.—The gantry crane is an adaptation of the overhead traveling-bridge type of crane to outdoor service where it is not desirable to erect an overhead structure on which to run the cranes. The crane bridge is mounted on movable trestles with trucks similar to those used on overhead traveling cranes. The whole structure moves back and forth on railroad rails on the ground. To meet special operating conditions, these cranes are sometimes constructed with one gantry leg—the other end of the bridge running on an overhead track; with a single or double cantilever bridge; or with a movable cantilever at one end. These cranes are made with spans up to 200 ft. or more and are used in storage yards and at docks for handling ore, coal, coke, cement, or manufacturing materials; in railroad storage and transfer yards, for general purposes and for transferring heavy freight; and at wharves for handling cargo.

CANTILEVER CRANES.—Several kinds of cranes fall within the cantilever group. Of these, the most common is the **hammerhead crane,** so-called because of its shape. It is extensively used for shipbuilding purposes and consists of a rotating cantilever structure secured to a pintle and mounted on a tower which usually has a portal base and is fixed to a solid foundation, but sometimes is mounted on trucks and travels on rails. Cranes of this type commonly have a radius of action up to about 100 ft. with a capacity of from 5 to 75 tons. They are made, however, with effective radii up to 190 ft. or more with a capacity of 50 tons at that radius, and up to 350-ton capacity at a shorter radius. Towers range in height to 200 ft. or more.

These cranes may be used singly to serve one or two shipways but usually are installed in groups with the cantilevers overlapping so that an entire shipyard, including ways and storage yard, may be served. This type of crane is used also for handling lumber in large storage areas.

CRANE AND HOIST ACCESSORIES.—Almost as important as crane and hoist equipment itself are accessories to be used under the hook, and care should be taken to select the proper attachments for the operations to be performed.

For handling **bulk material** there are buckets of four classes: grab-buckets of clamshell, orange-peel, or scraper design; drag-line buckets; turnover buckets; and bottom-dump buckets. These may be used on any machine having one or more hoisting lines.

For handling **barrels, lumber, railroad ties,** and large machine equipment, there are various kinds of rope and chain slings, grab-hooks, grapple-hooks, etc., also nets, cinch boards, and skips.

For handling **pig iron, steel, or iron scrap,** etc., the electric magnet has been widely adopted.

Many special attachments with hooks or grabs for handling **pipes** of various diameters have been developed. Also special grapples have been developed for handling **case goods** into and out of storage.

Track Systems

OVERHEAD TRACK OR MONORAIL SYSTEMS.—Overhead systems of transportation over a rigid track are often called monorails, although the terms tramrail, supertrack, and others are also applied to certain other forms of overhead trackage, and these terms also serve to designate the entire system (Fig. 39). The monorail, being suspended from the ceiling or other overhead portion of a building, may be installed and used without interfering with operations in the area under-

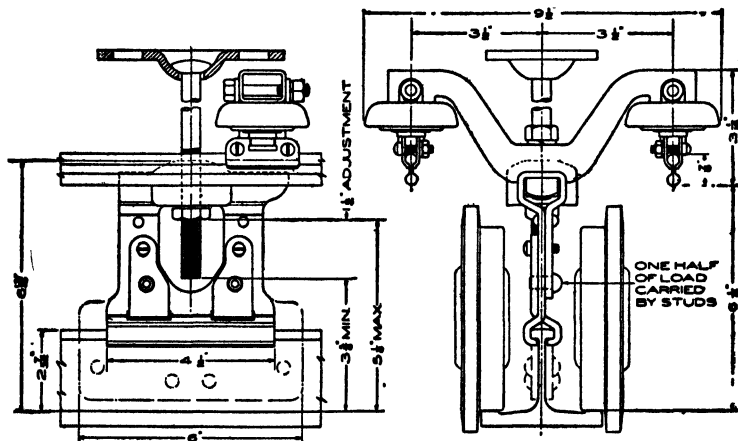



Fig. 39. Monorail Track System (Detail of tramrail suspension showing rail clamp, coupling, and hanger rod assembly)
(Cleveland Crane & Engr. Co.)

neath, and therefore offers some **advantages** over the industrial railway system which requires a clear floor area for the track and the operation of the cars. Monorail systems may consist of floor-operated traveling hoists using slings or skips to handle unit materials, or buckets for bulk loose or wet materials, in which case they are known as monorail hoists; but for continuous service they are usually run by an operator who rides

in a cab suspended on trolleys. Practically any kind of power-operated hoist can be used with a monorail system.

Switches and turntables in a monorail system can be manually operated, or electrically operated by remote control. In the latter case, photoelectric cells or indicator pins actuate the electric mechanisms so that the systems are fully automatic.

Capacities of monorail hoists run as high as 6 tons or more. Speeds of operation run up to 35 ft. per min. or higher, depending on the number of switches, curves, and other characteristics of the system.

The **monorail telpher**—now generally classed with other monorail equipment—is an electric hoist mechanism, usually cab-controlled, which is used for indoor or outdoor services in industrial plants, power plants, warehouses, machine shops, or wherever trackage for such service can be installed. In origin, the telpher is a carrier used outdoors on a cableway to bring raw materials like ore, sand, etc., from some distant point, such as a mine or pit, into an industrial plant for processing.

By using a proper hitch, trailer units can be made up into trains for operating behind monorail hoists or monorail telphers.

INDUSTRIAL RAILWAYS.—As length of haul, weight of articles moved, and amount of materials handled increase, it may become economical to install an industrial railway, but the tendency in this direction has lessened. The increasing capacity and adaptability of power-driven industrial trucks, and the convenience with which they can handle trains of small hand trucks or trailers, as well as the availability of tractor and trailer systems, have led to some extent to the installation of such equipment instead of railways, or the removal of railways in favor of the trucks and tractors. The latter are independent of trackage and can go anywhere in the buildings or yard. Where, however, routes for materials are definite, invariable, and in constant use for handling large quantities of heavy articles or bulk materials, the railway has a field. A typical case would be that of a foundry bringing sand or clay from an adjacent pit or a brick or tile plant moving in material from a clay pit.

The gage of track used is from 18 in. up, with 24 in. in greatest use. Weights run from 8 lb. per yd. up. It is not customary to class the standard 56½-in. gage track as an industrial railway installation, because such yard trackage is merely an extension into the plant of the siding from the outside railroad. The additional standard track in the yard constitutes merely extra facilities for car loading or unloading, car storage of empties or of loaded cars to be made up into trains, and car handling and switching.

Standard equipment is available for industrial railways. Locomotives of various kinds and capacities—steam, internal-combustion engine, compressed air, storage battery, trolley, or third-rail—are obtainable. Cars come in standard sizes and types, or can be made to suit the special purposes of any plant. The size and number of units to install depends upon the volume of work done, loading and unloading facilities, normal time in transit, number of loaded cars in transit or use at any one time, number of empties to have available for peak loads, distances to be covered, and the degree of flexibility obtainable in making up trains, switching, transit through the yard, and other operating factors. Possible

future changes and extensions should also be taken into account in planning an installation.

LOCOMOTIVE CRANES.—Locomotive cranes, as their name implies, are a variety of railroad equipment used for moving, loading, and unloading cars, and for other outdoor handling work. Some are fitted with railway trucks to run on standard-gage railroad track. Others operate on crawler treads so that they can move anywhere in the yard.

Cranes of this kind carry large booms which in some cases have been made as long as 170 ft. A block, and fall and cable rigging on the boom, and cables to raise and lower the boom, are the means by which the handling is done. Slings or tongs hung on the hook are used to lift boxes, bales, lumber, pipe, and other unit or packaged items. For handling loose materials, grab-buckets or dragline buckets are often attached. When iron or steel is to be handled, an electric magnet is used on the crane. Load capacities range from 5 to 10 tons up to as high as 160 tons. Couplings are attached to each end of the crane platform for moving railroad cars.

Such cranes can be swung around in a complete circle whose maximum radius of effectiveness for any load is determined by the tipping moment of the crane, unless the crane is blocked against overturning. The less the horizontal radius, the greater the load that can be lifted. The operating mechanism is located in the cab of the crane, and the gears revolving the crane mesh with a geared turntable mounted on the base of the crane.

Locomotive cranes are usually self-powered by steam boilers and engines, or diesel, oil, or gasoline engines, or they may be operated by electric current.

Portable Equipment

PORTABLE CONVEYORS.—Portable units of many of the types of equipment described in the foregoing pages are available in a variety of sizes to meet normal requirements. Portable conveyors such as the sectional chain-drag type used in mining operations are built in lengths up to 300 ft. Some of more common portable equipments in use are of pneumatic, chain-drag, cross-bar, apron, flat-belt, troughed-belt, bucket, twin-screw, and elevator types.

Portable equipment, in general, is subject to greater maintenance and deterioration than fixed equipment, because of the greater wear and tear resulting from moving it, the more unfavorable conditions attending its operation, and the fact that it has to be readily portable for low cost of moving, which frequently means sacrificing strength and rigidity to lighter weight.

TWO-WHEEL HAND TRUCKS.—Hand trucks of the two-wheel variety are constructed in many sizes and shapes, one of the commonest varieties being the baggage trucks formerly seen around freight terminals. They should be used only for irregular and infrequent service and short hauls of materials that cannot be handled effectively on skids or pallets because of the small quantity to be moved, or some special consideration.

FOUR-WHEEL HAND TRUCKS.—Trucks consisting of a platform on four wheels or casters are better than the two-wheel variety because of the greater loads which can be handled and the reduction of muscular effort in their operation. In many cases, such trucks are provided with a superstructure forming racks, bins, or shelves. Their use normally should be confined to short hauls and miscellaneous or intermittent service. Many such trucks, however, are used regularly to carry work from operation to operation and in such cases the truck serves as a storage place for work at machines before and after an operation is done. Often these trucks are made up into trains for delivery to other departments.

HAND LIFT TRUCKS.—Lift trucks are designed for handling articles or containers stacked on skids or pallets. A skid is a small platform

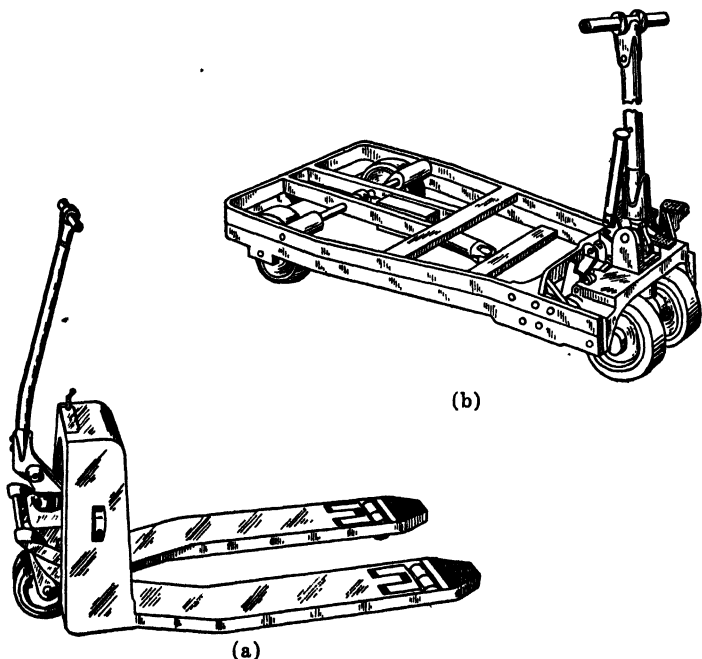



FIG. 40. Hand Lift Trucks. (a) Fork type for handling pallets; (b) Platform type for handling skids

on four legs, or on two stringers or continuous legs, one down each side, to raise the skid off the floor so that the platform of a lift truck will run beneath it and pick it up for removal to some point. A pallet is a

low skid with a continuous, or almost continuous, bottom instead of feet, so that the fork of a fork truck, and in some cases the platform of a lift truck, will go into the space between the top and bottom and lift the pallet and its load. Articles, packages, loaded containers, or anything that can be piled or stacked, may be put on the skids or pallets and transported to or from the storeroom, from workplace to workplace, into or out of finished stock, and into and out of freight cars for shipment between plants. For particular purposes, the skids or pallets may be provided with bins, racks, arms, or any other suitable carrying device.

Hand lift trucks (Fig. 40) are used for local work of the above kind where the distances of moving range up to about 75 ft. In the absence of power-driven lift trucks they will be used over all distances and for many purposes in a plant. Platform trucks have two wheels spaced at the width of the truck on the back end and two wheels close together under the handle in front. The wheels are usually steel, because there is no tractive effort which would cut the floor, but can be of composition, or rubber-tired. The handle is used both for pulling the truck and for pumping oil into the lower end of the hydraulic lift which elevates the skid platform clear of the floor for moving. When the load is to be set down, the operator presses down the check valve release with his foot, and the oil is forced into the other end of the hydraulic lift as the truck platform settles down to its bottom position and deposits the load on the floor.

Hand lift fork trucks for pallets have wheels at the back to bear on the floor when carrying loads. Hand lift trucks come in several designs and in standard capacities up to 8,000 lb. Loads of 4,000 lb. are as much as one man can conveniently move. For heavier work, trucks with higher capacities can be obtained. Loads carried in a multistory plant must be within the capacity of the plant elevators. Only light loads can be moved up ramps, unless a chain-and-dog pusher is installed on the ramp. Floors must be level, hard, smooth, and in good repair, or truck operation will be difficult and the steel wheels will cut the surface.

WHEELED JACK: LIVE-SKID SYSTEM.—The wheeled jack method of handling is similar to the hand lift truck skid system except

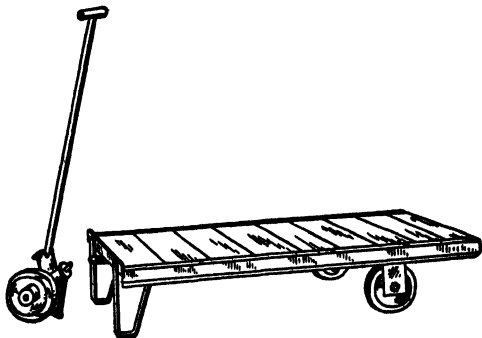



Fig. 41. Two-Wheeled Jack

that the skid is equipped with wheels at one end and legs and a coupling at the other. A jack mounted on wheels is run under the leg-end of the skid to engage the coupling, raise the end of the skid, and carry the load to the desired point, thus providing a combined four-wheel mobile handling unit. Such a method is frequently used when the skid is employed as a means of storing work in process at machines, or temporarily in the storeroom (see Fig. 41).

Self-Propelled Equipment

POWER-DRIVEN LOW-LIFT TRUCKS.—For heavier loads, longer distances, more continuous service, and quicker handling, the power-driven lift truck is used in preference to the hand lift truck. Each thus supplements the other. The power-operated trucks are driven by gasoline engines or storage batteries. Storage-battery trucks run at speeds of 5 to 15 miles per hour, gasoline trucks up to twice that speed, or higher. Capacities range normally up to 12,000 lb.

There are also electric motor-driven transporters having contactor control with forward and reverse push buttons in the steering handle for thumb-tip control. Storage-battery trucks require the installation of

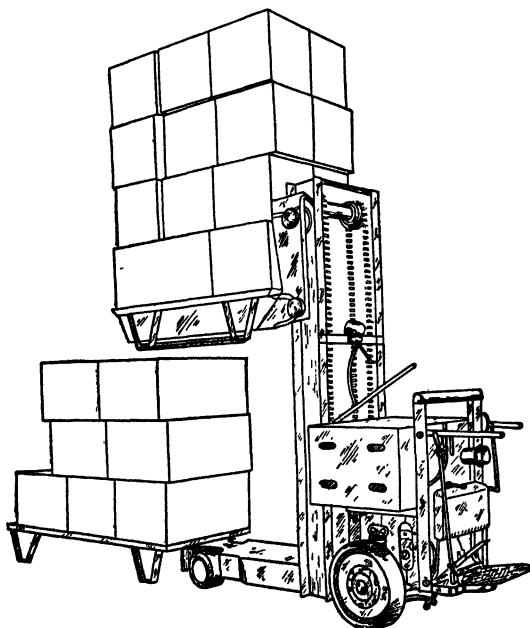



FIG. 42. Power-Driven High-Lift Truck

equipment to recharge the batteries daily. Under heavy service, trucks are often put on the charger during the lunch hour to keep up the power. Gasoline trucks can be operated continuously except during repairs. Maintenance and adjustment work, and especially lubrication, should be done periodically on all truck equipment, otherwise the heavy service and rough treatment the trucks receive will bring about rapid deterioration. Power-driven trucks usually have composition or rubber tires to prevent damage to floors, which, with steel wheels, would occur because of the tractive effort and heavy loads. Floors should be level, hard, smooth, and free from holes, ruts, or bad cracks.

POWER-DRIVEN HIGH-LIFT TRUCKS.—It is economical of space and time, and relieves floor congestion, to pile materials high in storage, or while temporarily awaiting further operations. The high-lift truck, formerly called a portable elevator, is used for this purpose (Fig. 42). It can also be used as a regular transportation vehicle like the low-lift truck.

In high piling of heavy articles, such as drums of oil, bales of cotton, hogsheads of tobacco, etc., the piling is done by raising the lift truck platform to the top of each successive tier and rolling or pulling the load onto boards or timbers on top of the pile, and back if the pile is deep. Reclaiming is done in the reverse order.

For smaller articles piled flat or boxed, skids are usually used to make up the unit loads, and then each successive skid load is elevated (see Fig. 42), run in over the skid load below, and lowered on it, the truck pulling out after the weight is off its platform.

Good floors are imperative for successful truck operation. Fig. 43 shows the tractive resistances of various surfaces.

Kind of Surface	Resistance, lb. per ton
Smooth concrete or wood block	30–50
Smooth hard mastic	30–50
Granite block, poor brick, etc.	50–70
Gravel	60–75
Clay or sand	200–300

FIG. 43. Tractive Resistances of Various Surfaces
(Industrial Truck Statistical Assn., Materials Handling Handbook)

FORK TRUCK: PALLET SYSTEM.—To obtain high economy in floor space and costs of handling unit loads, the fork truck and pallet system is now being widely used in handling package materials. The fork truck is a power-driven high-lift truck, with the lifting platform replaced by a fork of two or more flat, tapered prongs (Fig. 44). The entire lifting mechanism is tilted forward to assist in pushing the fork under a load, and tilted backward to assist in retaining the load while in transit. It is particularly adapted for handling pallets loaded with materials, but is also used to pick up and carry drums of oil or chemicals, rolls of paper, etc., and will handle loaded skids. It is effective in handling pig metal such as lead, tin, antimony, etc., directly on forks.

A **pallet** is essentially a two-faced skid consisting of two flat surfaces

held a few inches apart by cross stringers, the space between being for the insertion of the fork of a truck (Fig. 45a). Pallets are also made single-faced, sometimes in skeleton form, for lighter service, especially where they are moved by hand-lift pallet trucks and for one-time use to go along with the shipments they carry. Pallets may be constructed from inexpensive lumber at relatively low cost. Corrugated sheet-steel pallets are also available. The particular advantage which the standard double-faced pallets have over a skid lies in their flat under-surface which

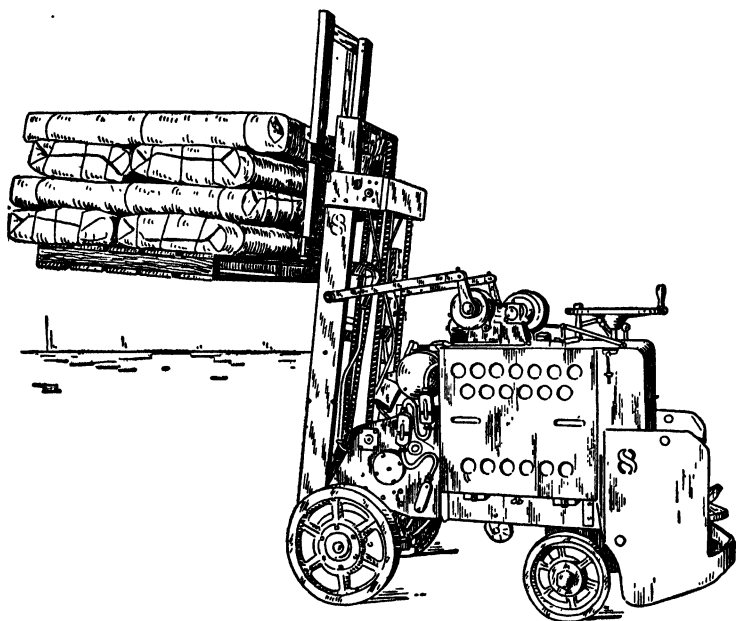



FIG. 44. Fork Truck for Handling Pallets

permits stacking of pallet loads one on top of another, often to ceiling height.

If items stored are susceptible to injury, or if in cartons, the legs of a skid would be likely to mar or crush them. Use of stringers instead of legs on skids distributes the weight somewhat, but for best protection, boards must be laid on top of each tier. Pallets, however, give the required distribution of load and eliminate the need for special protection of items on the lower platforms.

Such a method is highly effective for bagged sugar, flour, cement, packages and cartons, knocked-down corrugated shipping containers, fragile items of porcelain, and numerous other goods. The stacking of loads by this method results in most economical use of floor area. Two

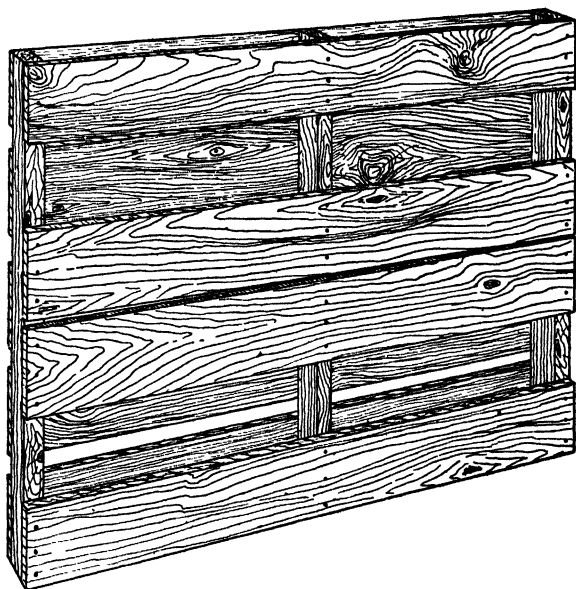



FIG. 45a. Typical Construction of Pallet for Operating with Pallet Hand Lift Trucks

or more pallet loads can be handled at one time providing the total load does not exceed the capacity of the truck.

Forks are interchangeable, with choice of long or short prongs. They can also be replaced with a bar for handling objects having a hollow center such as sections of sewer pipe, coils of wire, etc., or by a curved platform for special service. Some fork trucks are built as combination fork and crane trucks, having the advantages of both machines. Power lift trucks have been constructed with capacities ranging up to 30 tons to meet special requirements.

Capacities of fork trucks vary from 2,000 lb., to 10,000 lb., or more, depending on operating requirements. Fork trucks can pile pallet loads four tiers high. The average height of each unit load being about 4 ft., the fork will go up 12 ft. so that the top of the pile will be about 16 ft. from the floor. Some trucks are equipped with telescopic masts that permit tiering of pallet loads, under special conditions, to heights up to 22 ft.

A completely organized system of fork truck handling in an industrial plant is given later in this Section.

Toe Plates.—These are used between loading platforms and cars to serve as a bridge for fork or lift trucks (Fig. 45b). A useful check list of their design details is given in Fig. 45c.

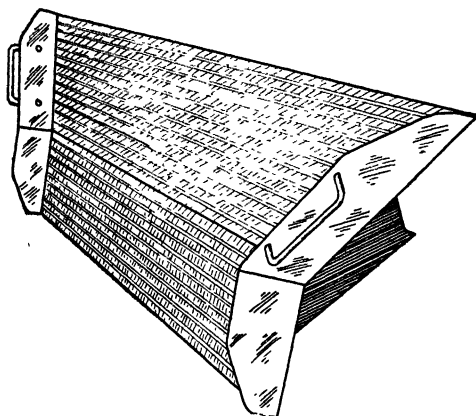



FIG. 45b. Toe Plate
(General Electric Co.)

HOW DO YOUR PLATES CHECK AGAINST THESE POINTS?

		CHECK
1.	Are they large enough for easy movement of trucks and loads into and out of cars?	Yes___No___
2.	Have they any means for locking into position so that truck wheels cannot kick them out of place? (Nails or spikes are not reliable and many times are left in the dock or car presenting accident hazards.)	Yes___No___
3.	Do they have a nonskid raised pattern tread to insure adequate traction in wet, snowy, or icy weather?	Yes___No___
4.	Are they arched or bent to accommodate height variations from dock to car?	Yes___No___
5.	Is their strength adequate to prevent bending under maximum loads?	Yes___No___
6.	Are there provisions such as a raised edge sill to prevent truck wheels from running off?	Yes___No___
7.	Can they be power handled by your trucks? (Manual handling causes accidents that result in crushed fingers and toes.)	Yes___No___

FIG. 45c. Check List of Toe Plate Requirements
(Materials Handling Machinery Co., Inc.)

HANDLING SHIPMENTS IN UNIT LOADS.—The economies of skid or pallet handling of materials in unit loads extend to the receiving and shipping of goods. Many products are now being strapped or wired on skids or pallets, for rapid handling and to prevent loss or damage; are loaded and stacked in cars, ships, or motor trucks by lift or fork trucks, transferred, if necessary, at terminals, unloaded by such trucks at destination, and moved to storage or point of use as unit loads (Figs. 46, 47a, 47b). Standard skids and pallets, constructed at low cost,

CARDBOARD

16 BAGS 1,600 lb.

60" APPROX.

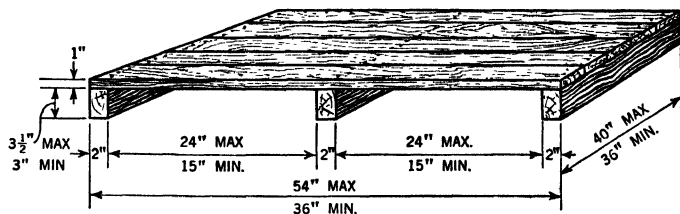
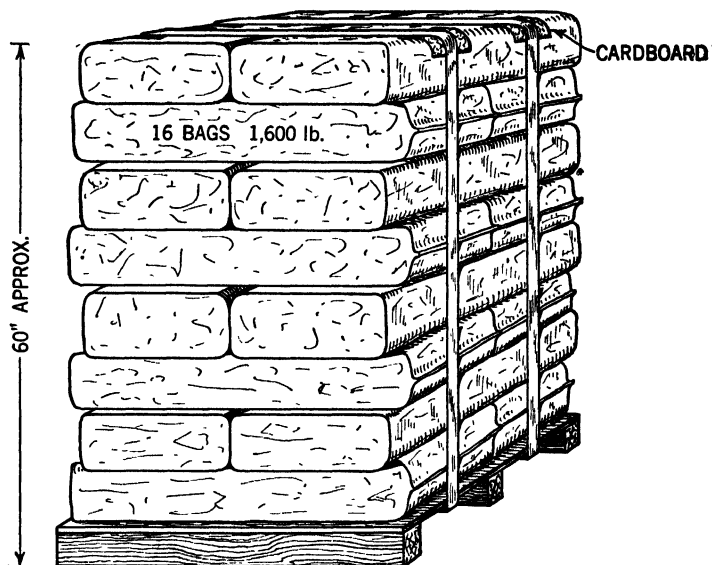



Fig. 46. Pallet Designed for Shipment of Bagged Soda Ash (Designed for use with hand pallet lift truck or electric fork truck. Load not to exceed 2,500 lb. Strapping is ¾" band. Corrugated box board corners may be used)

62" APPROX.

½" BAND IRON

PAPER PAD

APPROX. WEIGHT
840 lb.

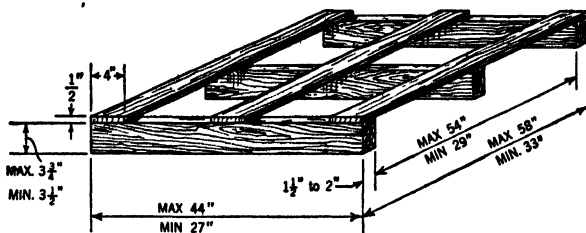
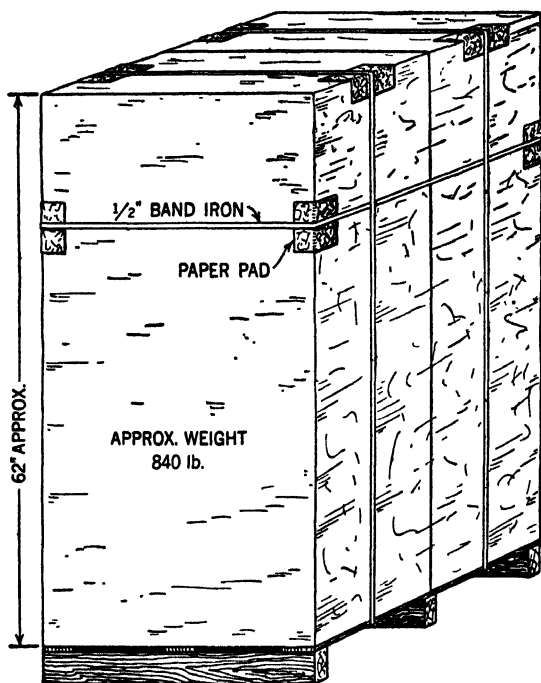



FIG. 47a. Low-Cost One-Way Skeleton Pallet for Shipment of Cardboard Packing Cases by Means of Hand Pallet Lift Truck or Electric Fork Truck

can be returned by the purchaser, used in his plant, or loaded with his own products for shipment to his customers. The cost of skids or pallets is paid for many times over by the reduced costs of handling.

At railroad and marine terminals it is desirable to make up unit loads on skids and pallets (Fig. 47b) if the goods are not so received, and carry them to their destination for unloading in such unit loads. Another method is to load goods on trailers, which are "racked" in the ship or car, "unracked," and run off into the terminal for unloading. The term "racking" here refers to blocking up the trailers to take the load off the wheels, for greater stability. Such plans greatly increase carrying capacity, and increase productivity of shipping operations.

ADVANTAGES OF UNIT LOADS.—The advantages of unit containers for low-cost shipping have been applied to the making up of l.c.l. loads at plants or terminals. The sorted shipments are loaded into large, closed containers, with capacities as high as 200 cu. ft., and transferred to and from motor trucks, flat cars, or ships by means of cranes or tractors. Handling of many packages several times through sorting, loading, and unloading is thus avoided and the cost is far less. The cost of moving unskidded shipments on a railroad has been found to be one-third for car loading, one-third to transport the car 100 miles, and one-third for unloading at terminal, that is, two-thirds for handling, only one-third for transportation 100 miles.

For large volumes of shipping by motor truck, there are not only trailer trucks but also demountable bodies so that some of the latter can be loaded while others are in transit and still others are being unloaded at delivery point. The power unit thus is almost constantly in operation rather than the truck and driver being idle during loading and unloading.

STANDARDIZATION OF UNIT-LOAD HANDLING.—The Materials Handling Division of the American Society of Mechanical Engineers has a representative committee, composed of members from the various kinds of shippers, transportation agencies, manufacturers of equipment, and users of skid and pallet methods of handling, who are working to develop standards covering practices for the usual kinds of materials and commodities shipped over rail, steamship, express, motor truck, and air lines. These standards will cover sizes and construction of skids and pallets, weights of unit loads, methods of stacking commodities on the platforms, strapping or wiring the loads, stacking heights of loaded platforms, provisions for distributing weights in stacking where articles are susceptible to damage, procedures in loading and unloading carriers and handling platforms into and out of storage, and similar problems. Steamship lines have been studying such questions for some time. Railroads and air transport companies are making similar investigations. A practice of having skids and pallets considered as dunnage when bearing loads may be brought about. A plan is also in effect to supply pallets throughout certain territories and exchange them among users so that in transit they may always carry loads instead of going back to vendors empty.

The Army and Navy have standardized on 48 x 48-in. double-faced pallets with three 4-in. deck spacers and spacing in lower decks for pallet hand-lift truck wheels or rollers to bear on the floor.

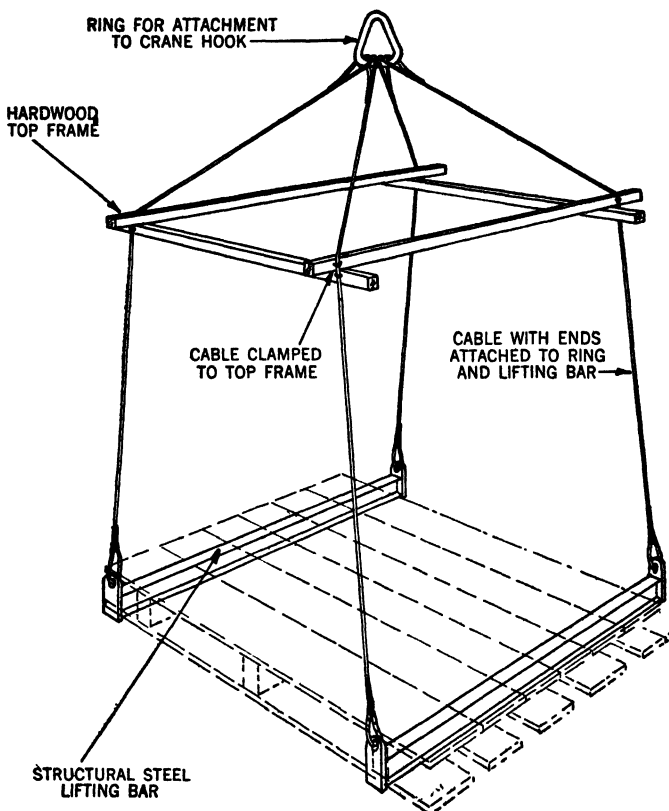



FIG. 47b. Cable Sling for Cargo Pallet
(Materials Handling Machinery Co.)

STANDARDIZATION OF TRANSPORTATION BOXES.—Kenneth MacGrath, General Manager, Eclipse-Pioneer Division, Bendix Aviation Corp., emphasizes the possibilities of a factory-wide standardization of shop transportation boxes which affords many economies. Such boxes are made to uniform outside dimensions to meet standardization requirements for handling and storage economies and are provided with special inside sections for specific parts handling. Such transportation boxes afford proper protection from damage due to rough handling of work and serve as useful holders of work at operators' machines or work benches. They also provide good stockroom storage containers and, on account of the uniformity of outside dimensions, are easy to handle in

a coordinated materials handling program. Internal sections may be arranged so that loaded weight does not exceed safe limits.

TRACTOR-TRAILER SYSTEM.—This system is essentially a haulage system, the tractor supplying the motive power and the trailers carrying the materials. The low initial cost and comparatively light weight of the trailers compared with power trucks, together with the lesser labor cost of loading, result in a low handling cost per ton. The major application of tractors and trailers is in the movement of large quantities of materials over relatively long distances, conditions frequently found in factories, warehouses, railway freight terminals, and steamship piers (Fig. 48).

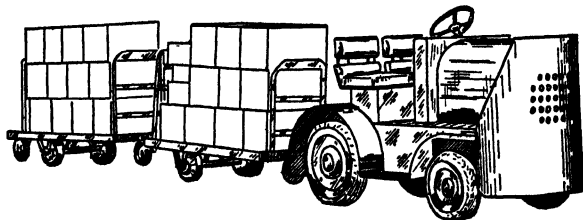



FIG. 48. Tractor and Trailer

Most tractors have running speeds, without load, up to 15 miles per hour and their capacities vary up to a draw-bar pull of 4,000 lb. or more at 2 miles per hour. A tractor delivering a draw-bar pull of 1,000 lb. in high gear will pull a 66-ton trailer load on smooth, level pavement at 2.6 miles per hour, or an 8-ton load on four trailers up a 10% grade. Tractors are usually powered by self-contained units of the storage-battery or gasoline-engine type. The number of trailers one tractor can keep in operation depends on working conditions such as time for loading, length of haul, speed at which the train can travel because of inclines, weight of loads, or nature of materials. Under normal conditions one tractor can keep three sets or "fleets" occupied, one loading, one under transportation, and one unloading.

When operating in close quarters such as between dock and ship and hatch on deck, rarely more than two trailers can be hauled effectively at one time.

Trailers are a **development of the four-wheel hand trucks** but are more strongly built and are equipped with coupling devices to connect them in trains. They are available with two- or four-wheel steer and can be provided with dump body or appropriate superstructures to permit the handling of practically any kind of materials. Elements of cost in tractor and trailer operation are given in Fig. 49.

In later paragraphs of this Section the operation of a complete tractor-trailer system in an industrial plant is described.

Advantages of Combined Industrial Truck and Tractor-Trailer Systems.—While the tractor-trailer system has definite advantages at distances of 500 ft. or more, it still has some disadvantages in that the

Cost of Operating Tractors

Operating Charges
- Labor:
  - Supervision
  - Driver's wages
- Supplies:
  - Oil and grease
  - Solution and water
  - Tires
  - If electric:
    - Energy—total kwh. for year at prevailing rate.
  - If gasoline:
    - Gasoline—total number of gallons used during year at prevailing price per gal.
- Maintenance:
  - General repairs
  - Daily repairs

Fixed Charges
- Insurance approximately $40 per $1,000
- Interest at 6% on investment
- Depreciation—15% covering 6-year period
- Garage rental

Cost of Operating Charging Equipment

Operating Charges
- Labor:
  - Operator's wages
- Supplies:
  - Oil and grease
- Maintenance:
  - General repairs
  - Daily repairs

Fixed Charges
- Insurance approximately $40 per $1,000
- Interest at 6% on investment
- Depreciation—15% covering 6-year period

Cost of Operating Trailers

Operating Charges
- Supplies:
  - Oil and grease
- Maintenance:
  - General repairs
  - Daily repairs

Fixed Charges
- Insurance approximately $40 per $1,000
- Interest at 6% on investment
- Depreciation—20% covering 4-year period
- Garage rental

Note: Total of these charges for total number of working days divided by total tonnage hauled during same period, will give cost per ton.

Fig. 49. Cost Items of Tractor-Trailer Operation

trailers must be manually loaded or unloaded, unless cranes are available. This disadvantage can be overcome by applying the unit-load principle—loading the trailers with pallet loads by means of a fork truck. This method, combining low-cost haulage by **tractor-trailer** with low-cost loading and unloading by the **fork truck pallet system**, will result in the lowest cost of handling materials over a wide, unrestricted area. In some cases handling is done by the use of a fork truck to do the pulling of trailers, and at the same time to carry a load on the forks. Tractor and trailers may have automatic couplers. This type of integration is yielding substantial economies in large industrial plants, package-freight terminals, and in ship loading and unloading operations.

SPECIAL FREIGHT CARS.—The railroads supply several special kinds of freight cars to facilitate quick handling. The gondola car with bottom-dump equipment is widely used for handling bulk materials such as coal, coke, and sand. Usually these cars unload on trestles below which there are storage bins, or they can discharge into hoppers below the tracks, from which the materials may be removed by bucket elevator, screw conveyor, or drag scraper conveyor. Sometimes the materials are allowed to fall on the ground and then are loaded into trucks by means of portable loaders. Other special cars are equipped with conveyors for trimming and unloading, the conveyors being built-in units.

While there are still a large number of freight cars with narrow doors, the modern cars are now provided with wide doors so that industrial trucks can enter to load or remove shipments. When the shipments are on skids or pallets, the work may be done in a couple of hours. Freight cars have also been constructed with end doors instead of side doors, so that assembled automobiles may be run into them, and run off at the delivery point, thereby saving the knockdown, reassembly, and boxing charges. In the automotive industry extensive use is made of leased cars with permanent metal dunnage. Cars can be equipped to accommodate special blocking, bracing, and securing of the lading.

Tank cars are in wide use for the shipment of certain chemicals, oil and gasoline, and bulk dry products, the latter being removed by self-contained conveyors. For unloading carload lots of bulking products in large quantity, car-dumpers are sometimes installed so that the cars can be run into and clamped to the revolving dumper which then overturns them and drops the materials into hoppers beneath the track.

INTEGRATED HANDLING SYSTEMS.—Such systems consist normally of a coordinated group of different types of equipment described in the foregoing pages. For example: a coal-handling system elevates coal by bucket conveyor to a point above the storage bin; the coal then slides into the bin by chute, and later is drawn from storage onto an apron conveyor which transports it to a hopper above screw conveyors; the latter move the coal horizontally and feed chutes placed over stoker hoppers. In manufacturing it is not unusual to find chutes, gravity roller conveyors, belt conveyors, and cross-bar conveyors tied into a single system. There is a proper combination of equipment for each set of conditions and selection should be made only after thorough analysis of handling requirements by a competent materials handling engineer.

Coordination of Handling with Production

NEED FOR COORDINATION WITH PRODUCTION.—Whatever the methods of production and production control in use in a plant, it is highly important to coordinate materials handling activities with the system for managing production. Good production planning will indicate at once the necessity for proper routing and dispatching of work to bring it through on schedule. Materials handling is the medium through which the prompt and correct dispatching of materials and work in process over the routes established is carried through on schedule to complete manufacturing and assembly operations on time to meet promised shipping dates. It is the service tying processing operations into a system of straight-line production.

CONTINUOUS AND REPETITIVE PRODUCTION.—In continuous process industries (chemical, cement, flour, sugar, oil, paper, etc.) materials handling directly ties together the sequence of processes necessary to manufacture the product, through the pipe line, gravity flow systems, and conveyors connecting the various operations. In fact, the materials handling system constitutes practically the closed chain of arteries through which the flow of materials passes from one machine or center of production to another until the final stage of completion is reached. The channels of flow are natural and accepted and provided as a matter of course. In repetitive types of manufacturing, constituting all kinds of mass production attended by mechanized parts production and assembly procedures, the planning and installation of materials handling equipment to cut down hand labor, increase output, and speed production is likewise an obvious and foregone conclusion. The mediums are installed in many cases as parts of the fixed plant equipment, just as in process industries. There is no other way to get the desired results. In both of these classes of manufacturing, however, there is still need for further improvement in materials handling so that inventories of raw materials and work in process can be substantially reduced through the efficiency of materials handling coupled with advanced manufacturing methods and good management.

INTERMITTENT PRODUCTION.—In intermittent-type industries—those producing largely to special order or making a considerable variety of products in limited-sized lots—there has been less tendency to do organized planning of materials handling activities because of the lack of mass flow of work through operations and less obvious opportunity to adopt product layout and set up standard work routes for a sequence of processes. However, special study and planning will usually reveal ways to set up efficient materials handling methods. The greater the variety of operations in such plants the less the attention that has usually been given to the possibilities for bringing about savings through better handling procedures.

SERVICE OF MATERIALS HANDLING TO PRODUCTION.—From even an isolated conveyor system installed to facilitate production of certain parts or assemblies there are several advantages to be gained.

1. Handling of operations is mechanized, releasing that much trucking or hand labor.
2. The route is fixed mechanically and materials and parts do not go astray.
3. Delivery and removal of parts are instantaneous, cutting out banks of work and delays in deliveries.
4. No identification tags or slips are necessary, no separate work orders are required, no records of individual operations are made.
5. Supervision of, and detailed attention to, transportation and flow of work are eliminated.
6. Work is kept up to schedule. It is naturally considered far more important to keep a production line moving than to keep individual machines occupied, because a whole chain of processes may become tied up. Therefore there is much care taken to get materials to and work away from such a line.
7. It is easier to keep track of the flow of work because of the chain of operations thus tied together.
8. From methods and time and motion studies, the work to be done at each station on the line, and the equipment capacity installed, can be balanced for even flow, kept at an efficient level, and paced at a fair rate.
9. Since the work is under a single supervision and not done in scattered departments, many of the inspections otherwise required can be eliminated without detriment to quality. At crucial operations, either the succeeding worker may immediately discover imperfect work already done, because he may not be able to do his work if the part is already spoiled, or the plan of patrolling or operation inspection—from sampling to 100%—may be applied at important operations but not at minor processes.

To a production engineer these advantages show at once a vast saving in the work of production control. Simplification or elimination of many steps is brought about in planning, routing, scheduling, dispatching, timekeeping and payroll work, materials control, inspection, and transportation. Consequently many individual operation and route sheets, work orders, material requisitions, inspection slips, identification tags, time and incentive wage tickets, are cut out because of the group work; the handling, sorting, summarizing, and recording of these papers is vastly condensed, and the reports, check-ups and controls are reduced to an easily handled responsibility instead of a maze and huge volume of wasteful paper work. Only at the start and finish of the line is it necessary to use forms and make records—two procedures instead of many, a few papers and records instead of thousands during the year.

Example of Savings.—One recorded instance of a study made on the manufacture of a small part, produced from .246 in. square stock in a length, finished, of 9 31/32 in., showed the savings indicated below from concentrating manufacture on one floor and conveyorizing the handling between operations (Bangs and Hart, Straight Line Production, Rep. 532, Alexander Hamilton Inst.).

Item	Savings
Operations	Reduced from 20 to 11
Floors traversed	Reduced from 4 to 1
Distance traveled	Cut from 7,167 ft. to 840 ft.
Sets of manufacturing records	Reduced from 13 to 6
Number of records posted	Cut from 4,900 to 250 per year
Forms filled out for production control	Cut from 67,000 to 3,000 per year

The following are examples of savings made from installations of package handling equipment (H. C. Keller):

To expedite the distribution of parts throughout a plant manufacturing aircraft engines, a complete installation of belt conveyor, gravity, roller flight, and overhead conveyor was made. The distance parts traveled was reduced from over a mile to around 1,600 ft., or nearly 67%. The parts inventory was cut to 1/12th its former size, a reduction of 91%.

A manufacturer of fire-fighting equipment was asked to produce oxygen cylinders for the armed services. Limitation of floor space available had reduced the production to a very low number of units per month. The installation of an overhead type of conveyor, combined with infra-red drying, increased production 600%, and relieved 10% of the workers formerly employed, for more important work.

A large printing plant always found it necessary during the Christmas rush to employ 18 people in the sorting room alone, and they frequently had to work overtime. A system of gravity and power conveyors was installed, and 8 people then could turn out even larger volumes without the necessity of overtime. In this case the entire system was paid for with the savings effected in a single Christmas rush season.

Combination of Many Activities Produces Economies.—It is not materials handling alone which produces all the advantages, but rather a combination of operation and methods studies, time and motion studies, equipment surveys, and plant layout studies, with the routing, scheduling, and dispatching techniques of production control as a coordinating medium and operating directive, which set the stages for standards of procedure that require materials handling equipment as the physical medium to make these improvements applicable and operative.

APPLYING TIME AND MOTION STUDIES.—Time and motion studies can be successfully applied to industrial trucking where the volume of work is sufficient to justify the expense of the investigation through the savings obtainable from better methods. Such studies

1. Determine the cost of handling.
2. Point out the delays imposed on groups of workers because of lack of synchronization of the various operations involved.
3. Disclose other defects in the handling cycle.

The form on which to record the data collected during the study provides not only for the usual information relating to the men, methods, equipment, materials handled, and other usual factors but also for information from which to determine the actual man-hours required per unit of work for each phase of the complete handling cycle. From such detailed records on the handling of a given commodity the analyst can determine the most economical method.

In a study made of trucking it is necessary to set up standard methods and instruct workers to follow them. Examples of written and graphical instructions for the purpose, as developed in a marine terminal, by Russell W. Allen Co. are given in Figs. 50, 51, and 52. In Fig. 50, the instructions cover:

1. Type of equipment to be used.
2. Number of men needed on each operation for efficient handling.
3. Performance expected.
4. Special instructions.

BARRELS AND DRUMS
Sheet 1

LOADING OF BARRELS AND DRUMS

INSTRUCTIONS:

1. Always handle barrels and drums on trailers. Do not hand truck or hand roll them.
2. Stow in Hold, preferably Aft. Next choice is the Lower Deck. Avoid stowing on Upper Deck unless there is space which will not otherwise be used. ("Wet" barrels should always be stowed in the Hold.)
3. Load 4 to a trailer when size permits: otherwise load 3.
4. Always "chock" the load at the **rear** when it is to go down-grade, and at the **front** when it is to go up-grade, so that the load bears against one of the pipe ends.
5. When only 2 men are loading trailers for stowing below deck, always have about half of the lot on trailers before starting into ship. In all other cases have about a quarter of the trailers loaded ahead of time.
6. When 4 men load trailers, they should finish loading the entire lot in three-quarters of the time needed by the ship men.

GANG MAKE-UP

Methods	Loaders	Tractor	Hatch	Shipmen
1. Load from Truck.......... Stow in Hold..............	2	1	3	4
2. Load from Floor........... Stow in Hold..............	4	1	3	4
3. Load from Truck.......... Stow on Lower Deck.......	2	1	3	4
4. Load from Floor........... Stow on Lower Deck.......	4	1	3	4
5. Load from Truck.......... Stow on Upper Deck.......	2	1	–	4
6. Load from Floor........... Stow on Upper Deck.......	4	1	–	4

Issued & Approved by:
General Agents ....

Checked by:

Wharf Superintendents..............
Chief Stevedore.....................

FIG. 50. Instructions for Loading Barrels and Drums

The time charts in Fig. 53 (Allen Co.) show the results that can be obtained by analyses of methods to determine the most economical procedure. In this chart the tractor-trailer method of handling drums and barrels from the dock floor to the hold of a ship is shown to be superior to the hand truck methods.

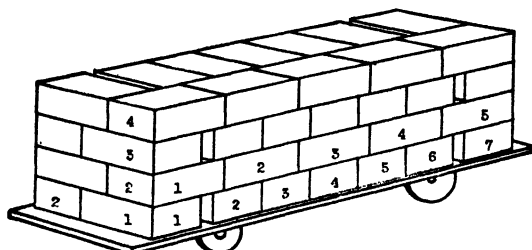
Charts analyzing the lowering and "racking" or blocking of a trailer load of materials on the lower deck of a ship are shown in Fig. 54 (Allen

Pork and Beans —1 lb.: 48 × 59½ lb. = 2,856 lb.
Tomato Juice —14 oz.: 48 × 57 lb. = 2,736 lb.
Spaghetti: 48 × 59 lb. = 2,832 lb.

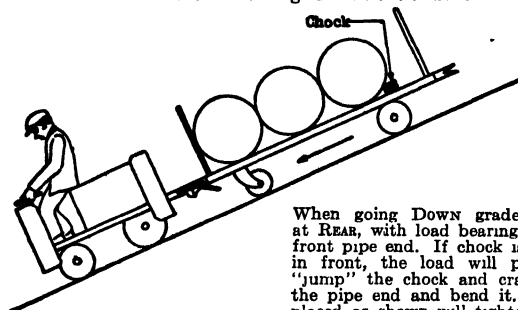
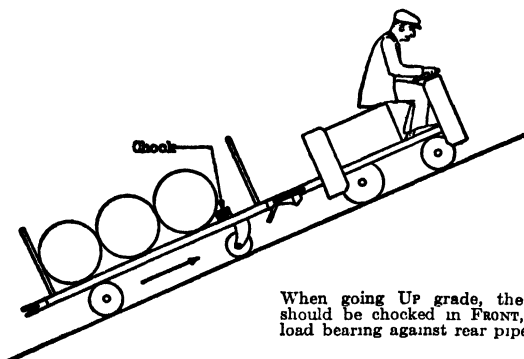
FIG. 51. Methods of Loading Canned Goods on Trailers

The chock should be at least 3 in. thick—a 2-ft. length of 2″ x 4″ is satisfactory.

FIG. 52. Hauling Barrels and Drums on Trailers: Method of Placing Chocks

Co.). The charts labeled A-1 and A-2 show the distribution of time for 7 men involved in the winch and "racking" operations with an over-all cycle time of 2.21 min. or 15.47 man-min. per trailer. Charts B-1 and B-2 show distribution of time for these two crews with a well-coordinated tractor service and a rearrangement in sequence of operations performed by the various individuals, requiring an over-all cycle time of 1.40 min. or 9.80 man-min. per trailer. Charts C-1 and C-2 show further

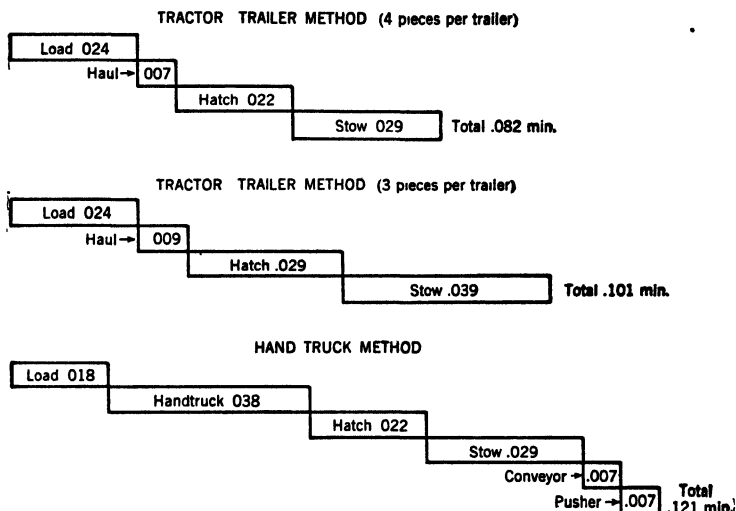



FIG. 53. Comparison of Man-Hours per Piece Required for Loading Barrels or Drums from Dock Floor to Hold of Ships, by Various Methods

gains made by the use of an improved lift-jack and a trailer support instead of the usual blocks, resulting in an over-all cycle time of .95 min. or 6.65 man-min. per trailer.

Recorders are available for installation on factory trucks which will register the running time of each unit.

PACKAGE CLASSIFICATION.—Where a great variety of packages are handled manually in loading or unloading trailers or similar vehicles, standards of performance or labor cost can be determined without specific study of that commodity, by applying standard unit times for handling certain classes of packages. Fundamentally, within the limits of manual handling, the **time required for handling materials in cartons varies with the volume and weight of the package being handled.**

WINCH OPERATION

A - 1 Typical present winch operation

B - 1 Waiting time decreased by improved racking method in Fig. B - 2

C - 1 Waiting time almost eliminated by improved racking method in Fig. C 2

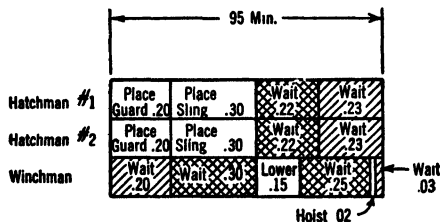
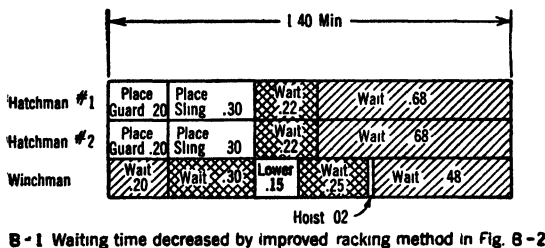
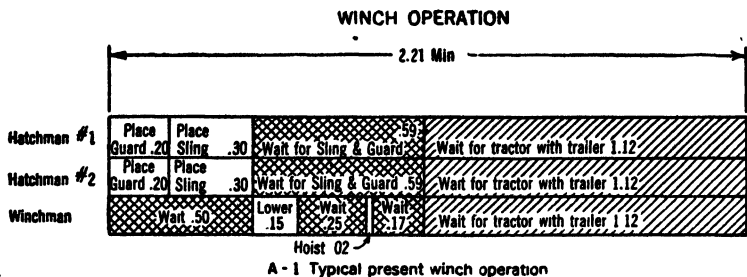



FIG. 54. Analysis of Ship Loading Operations

The factors and other data shown in Fig. 55 (Allen Co.) indicate a simple method of classification that has been found practical for this purpose.

On the basis of the combined volume and weight value for each class, it would appear that a small, heavy package would require about the same handling time as a large, light package, since they have a common value of 4.

STOWING OPERATION

2.21 Min.

Man #1	Push 40	Positions 14	Get Block 29	Rack 26	Return 16	Wait .52	Unsling 27	Remove Guard 17
Man #2	Push 40	Positions 14	Wait 29	Rack .26	Return .16	Wait .52	Unsling .27	Remove Guard .17
Man #3	Push 40	Positions .14	Wait 29	Rack .26	Return .16	Wait .52	Wait 44	
Man #4	Push 40	Positions 14	Wait .29	Rack 26	Return .16	Wait .52	Wait 44	

A - 2 Typical present racking operation on Lower Deck.

1.40 Min.

Man #1	Push .40	Positions .14	Rack .26	Get Block .29	Return 16	Wait 15
Man #2	Push .40	Positions .14	Rack .26	Return 16	Wait .44	
Man #3	Push 40	Positions .14	Rack .26	Return 16	Unsling .27	Remove Guard 17
Man #4	Push 40	Positions .14	Rack 26	Return 16	Unsling 27	Remove Guard .17

B - 2 Performance possible by rearranging sequence of work- block, etc.

.95 Min.

Man #1	Push 40	Positions .14	Rack 10	Remove Guard 17	Return 16
Man #2	Push 40	Positions .14	Rack .10	Remove Guard .17	Return .16
Man #3	Push 40	Positions .14	Return 16	Unsling .27	
Man #4	Push 40	Positions .14	Return 16	Unsling .27	

C - 2 Furthur improvement by use of trailer support.

for Racking Trailer Loads of Freight

Actual observations show the following times for handling packages from floor to trailer or vice versa:

Package Value	Man-Hours per piece
2	.0022
3	.0036
4	.0050
5	.0063
6	.0077

With these basic times it is possible to set standards for this type operation for handling any package material falling within the volume and weight range covered by the classes. These standards may be combined with the basic times required for mechanical operations such as hauling trailers by tractor, etc., to establish standard man-hours and unit labor cost for the complete handling cycle. Appropriate percentage allowances for fatigue, etc., are added to the basic time values to form the standard times set on the work.

Class	Volume Range, cu. ft.	Assigned Volume Value	Weight Range, lb.	Assigned Weight Value	Combined Package Value
Small—light.	Up to 1.9	1	Up to 24	1	2
Small—medium. . . .	Up to 1.9	1	25–49	2	3
Small—heavy	Up to 1.9	1	50–80	3	4
Medium—light	2.0–3.9	2	Up to 24	1	3
Medium—medium . . .	2.0–3.9	2	25–49	2	4
Medium—heavy. . .	2.0–3.9	2	50–80	3	5
Large—light.	4.0–6.0	3	Up to 24	1	4
Large—medium. . .	4.0–6.0	3	25–49	2	5
Large—heavy	4.0–6.0	3	50–80	3	6

Fig. 55. Package Classification for Handling by Industrial Truck

Organized Materials Handling Systems

PLANNING FOR ORGANIZATION.—In planning to organize a materials handling department, it is difficult to lay down rules which would cover the needs of every factory organization. In many industries such departments have not been definitely segregated, but Fig. 57, appearing later, illustrates an organization chart which could be adapted to many plants.

Regardless of the organization, the duties of a materials handling department should be: (1) to study the characteristics of raw materials and products that have to be handled; (2) to classify them into analogous groups with the knowledge of quantity to be handled, etc.; (3) to know what materials or groups of materials are to be moved from what point to what point; and (4) to establish the most effective routing and dispatching. If the product is standard and uniform and processing is continuous, it is not difficult to secure all the necessary information and a large personnel is not necessary.

Where there are numerous departments and overlapping operations, it is essential that materials handling be considered as a definite part of general factory planning. In many plants the functions of receiving, storing, transportation, and shipping are part of the materials handling program. The importance of arranging equipment for the most direct flow of material through the plant is evident. Plant layout charts indicate how to study the flow of material to determine any criss-crossing paths with resultant losses. Charts will also show how rearrangement of machines will save floor area, make for more direct line of travel, avoid congestion, and bring about a better operation.

PLANT-WIDE DEVELOPMENT OF MATERIALS HANDLING.—When the plan of conveyorization is expanded to include all sequences of operations which can be associated together under product layouts, the advantages extend to all such conveyor lines. Further improvement and savings result from the use of modern industrial truck equipment under an organized system of operation. The trucking system interconnects the processes carried out on different conveyor systems and forms a flexible, rapid means for such work and for other work which is not conveyorized. In some cases, of course, the trucking system may be the main, if not the only feasible, method to use, because of the way the plant is laid out and the manner in which operations must be carried on.

It is important that the materials handling department establish complete cooperation with the stores department, for the proper methods of piling, separation of lots, and handling of goods in storage, as well as storage equipment, play an important part in handling materials.

Through this universal coordination of materials handling the greatest service to production and the lowest unit costs are brought about. Engineering studies by experienced and broadly informed engineers are necessary to obtain such developments and economies, and handling, as a service function, must be studied from this angle, not from the standpoint of merely facilitating some difficult or slow lifting or transporting operations as isolated cases.

When better handling has been developed and the proper equipment has been obtained and put into operation, however, there remains the need for good management of the services on the part of those in charge of such work, and understanding by plant executives of the benefits to be derived by continued study and capable direction of plant handling activities.

ROUTING AND DISPATCHING.—Methods of routing and dispatching trucks are determined by the flow of work. Their purpose is to assure having trucks available when and where the flow of work demands and to achieve this result as cheaply and directly as possible. The problem is simplest in the heavy industries where one or more trucks are frequently employed continuously in the handling of work from one machine to another. It grows more complex as the number of distinct movements of material increases.

In a small plant, in which all handling operations are performed by one truck, the operator follows a routine of visiting the manufacturing departments in rotation. By means of lights or a factory call system the operator can be summoned to any part of the plant in case materials on hand are seen to be running short or finished materials are beginning to congest.

In larger plants employing a number of trucks for interdepartmental transfer work, the movements have been grouped into routes and transfer points where the routes intersect. One or more operators are assigned to each route and their job is to see that the routes are continuously and adequately served. For serving departments between which the traffic is relatively small, the scheduling of trips at regular intervals is steadily gaining favor in preference to the plan of dispatching trucks as called for by the foreman concerned. With schedules properly established and dependably maintained, foremen not only find it easy to plan

accordingly in requisitioning supplies and preparing their outgoing materials for pick-up, but also they receive better service than could possibly be rendered by the same number of trucks operating under the less orderly dispatch plan.

It is good practice to make a **layout of routes for materials handling** where there are several buildings in a manufacturing plant. An illustration of such an arrangement of routes is given in Fig. 56, appearing later, where the buildings are shown and the paths followed by the trucks are indicated by dotted lines.

MATERIALS HANDLING MANAGEMENT.—The clearer understanding which has developed within the past few years of materials handling as an integral function of plant operation has led to its organization as a separate activity in a number of progressive manufacturing companies. This trend has been especially noteworthy in companies having several plants, in many cases at different locations. Even though the lines of product may be different, the materials handling activities became recognized as having many elements in common. This phase of the question was more strikingly brought out in cases where some plants were suppliers of parts to others in the company, many materials were common, and there was a high volume of interplant shipments criss-crossing throughout the different units of the company.

The huge losses incurred through lack of standardization of materials handling methods, the large amount of repackaging and rehandling involved, the complication of incoming shipments from many vendors who often sent materials or parts to several or all of the plants in the company, and the difficulty of furnishing service throughout the company, all pointed to the obvious need for centralization of authority over the work to coordinate methods, standardize equipment, adopt identical practices as far as possible, and lower the high costs of miscellaneous, uncontrolled, and wasteful practices.

Among the companies which have centralizing basic materials handling activities to a considerable or fairly complete extent are the General Electric Co., Westinghouse Electric & Manufacturing Co., E. I. du Pont de Nemours Co., American Can Co., and certain other pioneering organizations.

Since some variety in methods is necessary to adapt handling procedure in each plant to its own immediate problems and requirements, the plan under centralized direction has been built largely along the lines of partial decentralization. While one directing head will guide the developments to gain the greatest over-all simplification and economy, there must be a materials handling supervisor or engineer in each plant to apply the activities locally according to the conditions and requirements of his own outfit. Gradually the best practices in each plant, of course, are communicated to the others and a similarity of practices and an upgrading of materials handling efficiency spreads through all the plants. The plan works best, however, where each man can meet the needs of his own plant as they vary from period to period with the kind, amount, complexity, and urgency of the orders under manufacture and the work going on in the plant.

The methods followed and the results secured can best be appreciated by a review of illustrative cases where such work has been centralized

throughout a company under a materials handling executive or manager. A man with this duty fills a staff function because his activities do not go down a single line—as, for example, those of a milling machine department foreman or a welding shop foreman—but criss-cross throughout the entire organization and call for just as much uniformity and coordination as the activities of the methods engineer, the personnel director, or the director of safety.

INTERPLANT COORDINATION OF MATERIALS HANDLING.—The General Electric Co. has nine major works and materials handling throughout the entire company is coordinated by a committee consisting of a representative from each works. The chairman is located at the general office in Schenectady.

Each works has its own organization for the management and operation of materials handling activities. The organization varies in the individual plant. At the Pittsfield works, for example, there is centralized control. All the equipment—that which operates entirely within departments in the plants as well as that used for transporting material between departments—is under the supervision of one man, the supervisor of transportation. He reports to the general superintendent of the plant.

The basis upon which the activities of the coordinating committee are founded and the general developments brought about, have been outlined in the following summary by H. J. Beattie, chairman:

Objectives. The objectives of the committee are to select the best methods of handling, obtain the necessary equipment, and put it into operation.

Fundamentals. There are two fundamentals in selecting methods and equipment.

1. **"Time is short" and above all, materials handling methods must be** time savers. The acid test of any materials handling system is its effectiveness in realizing the maximum machine utilization and man-hour productivity in the manufacturing departments. Studies of common manufacturing operations, such as punch press, drill press, lathe, grinding and subassembly, show that from 10% to 80% of the operator's time is devoted to ordinary materials handling. The average is around 20%.
2. **Flexibility** is a qualification of prime importance when selecting handling equipment. The question of flexibility is particularly vital during war periods when manufacturers are called upon to make transition from nonwar production to war production and must look forward to the reverse transition after the war.

Systems. In the various plants are found all of the many handling and transportation systems. In general, the various systems have well-defined fields of usefulness and are supplementary to one another rather than competitive. A broad classification of them is as follows:

1. **Standard gage railroad.** Locomotives are used for switching and spotting the incoming and outgoing railroad cars. To a minor extent, they are used along with the company-owned railroad cars to transport large, bulky materials between departments and noncombustible refuse to the company dumps.
2. **Motor trucks—highway.** This equipment consists of both gasoline and electric street trucks, and gasoline truck-tractors and semi-trailers. They are used primarily for the transfer of material be-

tween departments and also some between the various works or units of the company.

3. **Industrial tractors and industrial trailers.** Both gasoline and electric tractors are used to pull the trains of yard trailers or industrial trailers, and constitute the chief means of transportation for interdepartmental shipments in the works. They have the advantage of entering the buildings and even going to upper floors, as compared with the limited use of street trucks.
4. **Industrial trucks.** The industrial trucks are almost entirely battery operated, and include fork trucks, platform lift trucks, and a few fixed-platform cargo trucks. They are used for unloading and loading freight cars and street trucks, for handling materials in and out of stockrooms and warehouses and also for moving work in process materials within the manufacturing departments themselves.

Trends. There is a definite trend toward moving materials in larger bulk or unit loads, as this practice saves time and eliminates labor in handling and rehandling in small packages. The more specific trends in the use of the various kinds of equipment are:

1. **Standard gage railroad.** The diesel-electric locomotives are rapidly superseding the trolley and battery locomotives for switching. The transfer of materials between buildings within the works, and between works, is going more to truck-tractors and semi-trailers rather than to railroad cars.
2. **Motor trucks.** The trend with this equipment is toward a greater use of truck-tractors and semi-trailers rather than straight trucks.
3. **Industrial tractors and trailers.** This system is the backbone of the interdepartmental transportation system within the works. It employs an increasing number of battery-operated electric tractors and some gasoline tractors.
4. **Industrial trucks.** During the last six years the company has developed and expanded an industrial truck system known as the fork truck pallet method in all the works, which proved to be a lifesaver in meeting the materials handling demands caused by the tremendous increase in war production.

More than half of the investment in vehicle handling and transportation equipment over a period of six years was for fork trucks. During this period, 373 fork trucks were put in operation.

USE OF FORK TRUCKS AND PALLETS.—Further data on the company's methods (C. H. Barker, Jr., Mech. Eng., vol. 63) show the extent to which materials handling activities have been developed in the Bridgeport plant. Fork truck and pallet methods are employed not only for handling inside the plant but also extend back to arranging with shippers to send in materials on either closed or open-faced pallets, so that freight cars can be unloaded rapidly and the materials moved into storage, and sometimes later to point of use, without removal from the pallets until needed. Coiled steel arrives in a similar manner, stacked on open-faced pallets. Materials requiring greater care in handling likewise come in on pallets, such as the fine wire on spools, with a top protector.

Pallets.—A standard 48 x 48-in. wood pallet has been adopted for considerable of the handling in the company. Since such pallets must often be handled by hand pallet lift trucks as well as fork trucks, it is necessary to provide openings on the lower surface of the pallet for the outer supporting wheels of the truck platform to bear on the floor during

transportation. Such openings, 6½ in. wide, are placed about 6 in. from each end of the pallet, and the wheels at the end of the truck go down through the far opening as the lift platform raises the pallet from the floor.

Pallets used are made of soft or hard wood, combined wood and steel, or all steel. Where corrugated steel skids have been profitably used, often steel pallets are likewise best. A combined steel and wood pallet is also used in the General Electric Co. It is made of hickory slats and corrugated steel stringer, the wood edges protected by metal. While such a pallet costs about twice as much as wood, it is far more durable and therefore more economical than an all-wood pallet under hard general usage.

Since fork trucks used in handling materials to or from freight cars for transportation within or between plants, or from vendor to buyer, must go over a bridge or ramp to get from shipping platform to car and back, it is necessary to provide safe and convenient bridge-plates. In the bridge developed by the General Electric Company the use of heavy plate has been avoided by providing reinforcing ribs capable of sustaining the concentrated weight under the uprights on the fork trucks. These reinforcing ribs also prevent the bridge-plate from shifting and avoid the necessity for nailing or fastening it in position. A guard rail at each side of the bridge enables trucks to make short turns without skidding off down between the platform and the freight car. A chain can be stretched between the two handles at the end of the bridge-plate so that a fork truck can pick up the plate and move it to or from the car doors. (See Fig. 45b).

Advantages of Pallet Handling.—Barker stresses the following advantages of fork truck and pallet handling:

1. Reduced breakage or spoilage from improved and reduced handling.
2. Better utilization of manufacturing equipment.
3. Unit-load principle facilitates the maintenance of perpetual inventory, records or balance-of-stores cards.
4. Promotion of cleanliness and good housekeeping.
5. Possible damage to materials from sprinkler heads is confined to areas underneath them, because materials are raised 5 to 6 in. above floor level and therefore will not be affected by a wet floor.

Pallet handling also has marked advantages in connection with tiering.

CENTRALIZED MATERIALS HANDLING.—Methods in use at the Pittsfield plant of the General Electric Co. have been described by Mills (Iron Age, vol. 142) as supervisor of the system in this plant. Parts and products ranging in weight from 2 ounces to 200 tons are handled. The plan of operation is based largely on the use of fork trucks and pallets for direct handling and also to feed to and from the other transporting equipment comprised of tractors and semi-trailers and railroad cars.

The plant covers 92 acres of rolling ground, and roadways have steep grades up to 6%. Ramps also run to the second stories of certain buildings and have grades up to 10%. There are 159 buildings—several of 4 and 5 stories—with 52 acres of floor area and housing 92 departments. A simplified diagram (Fig. 56) shows the layout, the zones A, B, C, and

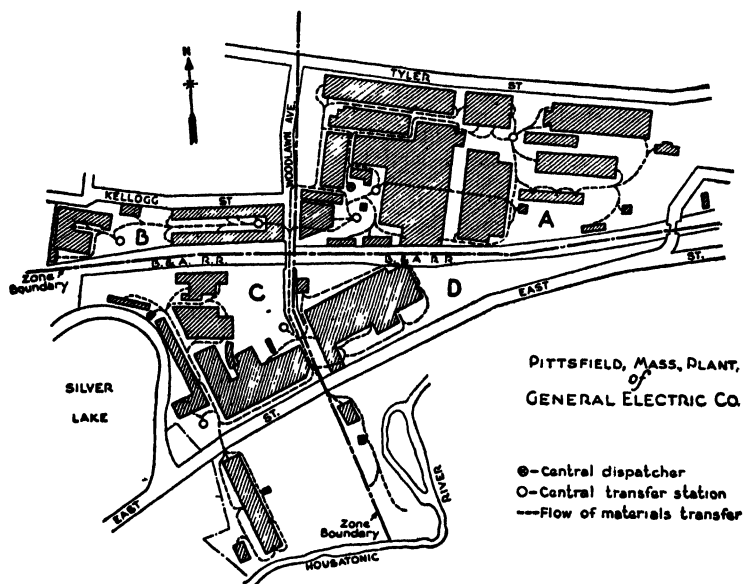



FIG. 56. Industrial Trucking Zones Covering an Entire Plant

D being given over to the manufacture and handling of different products.

Materials handling problems and studies have brought about many improvements, such as large elevators with high weight capacity, development of tractors with special gear ratios to negotiate the steep grades, and similar advances.

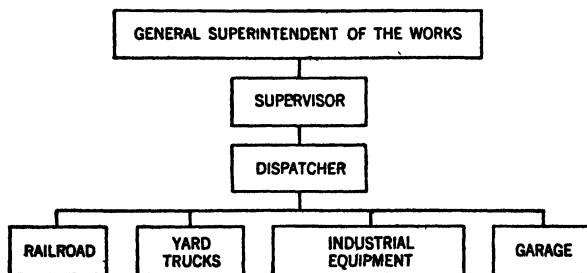



FIG. 57. Organization Chart of Transportation Department

Since 1928, a transportation department organized fundamentally as shown in Fig. 57 has carried on all plant transportation. Under this plan all such services have been coordinated so that equipment is kept up to date (60% was found to be obsolete when the new department took over) and departments in which considerable idleness of trucks and drivers had existed, because of intermittent demands, are now served efficiently by the central transportation department.

Highway Tractor-Trailer Service.—The tractor-trailer system was adopted for all highway service within the plant. Much of the prior plant railroad service was transferred to tractor-trailer handling, which has been further improved in efficiency by coordination with fork truck and pallet handling. Handling of finished transformers by 10-ton tractor-trailers cut the former railroad haul (under complicated switching) of 3 miles to 500 ft.—the actual distance between buildings—reduced handling time from 24 hours to 1 hour, and lowered cost 60%. So much trackage and rolling stock was eliminated and floor space saved by the changeovers that 2 diesel-electric switching engines and a locomotive crane were then able easily to handle all the many inbound and outbound freight cars without delays.

Factory layout of departments and machines is now planned with the needs for efficient materials handling for rapid and low-cost production fully in mind. The transportation department, in turn, is able to organize its facilities to handle all moving of equipment during changes in layout with a minimum loss in production time.

The supervisor of materials handling has a dispatcher, four foremen, and five group leaders assisting him. Equipment is distributed as follows:

2	Diesel-electric switching engines
1	Locomotive crane
7	Flat cars
5	Semi-tractors
42	Semi-trailers
10	Highway trucks
23	Electric tractors
5	Gasoline tractors
297	Yard trailers
11	Low-lift trucks
29	Tier-lift trucks
5	Baggage trucks
10	Fork trucks
447	Total pieces of equipment

COORDINATION WITH PLANT OPERATION.—Operation of the transportation system is coordinated with the work of the factory planning department. In this manner, time in production is saved and operating costs, in both manufacturing and materials handling, are held to economic levels. The dispatcher directing the daily activities has telephone connection with all 92 departments from which requests may come for service other than that supplied on the regular routes. A voice-amplification system, with a micrometer on the dispatcher's desk, enables him to give instructions over the loudspeaker to the truckers who are to take care of such work. This plan provides quicker response to

such requests and eliminates the former practice of having drivers come into the dispatch office on each trip through the central transportation yard.

EXAMPLE OF COORDINATED HANDLING SERVICE.—The handling of lightning arresters presents a typical case of coordinated handling between plants as well as within the plant. The porcelains come in from the Schenectady Works, stacked on pallets, 14 to a tray, for car loading and unloading by means of a fork truck. This method of handling saves 75% of the former costs for such work. Unloading is done to yard trailers which deliver the trays to a storeroom where they are removed and stacked, at a saving of 75% in handling costs and also 30% in floor space. Fork trucks carry the stacked trays from storeroom to factory floor, where manufacturing operations on the lightning arrester are served by conveyor systems. Cartons into which the arresters are packed as they come off the assembly line are placed on pallets which are for delivery to the warehouse. To prevent crushing of cartons during transport and when stacked in the warehouse, the pallets are placed in open-end crates on frames, two to a frame, so that the weight of the upper pallet loads is carried to the floor. The frames remain with the pallets when the lightning arresters are taken from the warehouse for shipment on railroad cars.

ADVANTAGES OF CENTRALIZED CONTROL.—The following advantages of centralized control of materials handling are listed by the supervisor:

1. A 30% reduction in handling costs and equipment investment.
2. Efficient use of equipment. Departments which otherwise would have trucks in use only part of the time are now served by trucks which the transportation division uses all the time.
3. Replacement of obsolete types of equipment by new equipment which cuts handling time and reduces operating costs. Trucks usually become obsolete in 10 years.
4. Development of new methods. Only through consolidation of activities could the fork truck method of handling have been applied so effectively to cut costs and speed up service.
5. Progressive improvements in material handling service throughout the entire plant to reduce over-all manufacturing time cycles, keep materials moving through production, and cut down inventories of stored materials and work in process.
6. Better maintenance of equipment through inspection and servicing —a factor often badly neglected under a noncentralized system. Moreover, within a period of 8 years, annual maintenance costs were reduced from $85,000 to $47,000.

AN INDUSTRIAL TRUCKING SYSTEM.—In the Westinghouse Electric & Manufacturing Co., the transportation of materials in, and between, divisions, as described by E. W. Simpson, is a vital factor in maintaining high production activity. An industrial truck transportation system is the medium that connects the various manufacturing departments and keeps them operating on schedule. To facilitate and speed up the flow of materials between departments, these materials have been divided into two classes—large and small—or shop express material and all other items outside of shop express specifications.

The shop express system was organized to eliminate the carrying of

small items by large trucks. Shop express includes all material weighing up to 70 lb. and measuring 48 in. in the largest dimension. These limits on shop express restrict the material transported to objects which can be handled easily by one man. The shop express trucks have special triple-deck bodies with several small compartments to facilitate the handling of tote pans and exceptionally small material.

The shop express system has been a big help in improving transportation in general. All material beyond shop express limits is taken care of by the regular trucking set-up. Thus it is possible for truckers and shippers of major items to devote their time mainly to large materials, knowing that shop express will take care of smaller items on scheduled runs.

Layout into Five Routes.—For shop express purposes, the plant has been divided into 5 routes, each route consisting of 14 stops or benches, as they are called. All benches are numbered for identification purposes. The routes have been so planned that the drivers have no trouble maintaining a 2-hour schedule. The benches are located on the aisles, easily accessible to both shippers and truckers. There is a central station where the five routes converge, which is used as a transfer point and mail depot (the pick-up and delivery of shop mail is a regular function of the shop express system). This central station affords enough room for all trucks so that loads can be transferred with a minimum of lost time.

Tagging Shipments.—Material to be shipped by shop express is tagged in triplicate by the shipper, with the sending and receiving sections plainly marked. The tags are numbered. The shipper retains one copy of the tag for his own records; the trucker retains one copy after stamping it with the number of the bench to which the material has been delivered; the last copy remains with the material for the receiver's information. The trucker's copy is kept on file in the transportation office for three months. Thus, there is a definite check on all material shipped by shop express.

Three Major Trucking Zones.—There are three major trucking zones within the East Pittsburgh Works. Each zone is serviced by a fixed number of trucks operating from a centrally located dispatch office within the zone. The number of trucks assigned to each zone was established according to the known activity within the zone. A dispatch clerk at the station receives requests for trucking service from sections in his territory. He gets as much information as possible about the load to be carried so that he can properly plan the use of his equipment and the trucker's time. A load may be carried on the bed of a flat truck, on skids, or by trailer. Each station operates both flat and lift trucks and also, upon request, supplies trailers or trays for transportation purposes.

The dispatch clerk endeavors to schedule his truckers so that they will always have a load to carry, or lose as little time as is possible in traveling empty. Truckers have been instructed to call their dispatch clerks upon delivering a load, if something has not already been scheduled for them.

Some material is shipped between zones. The dispatchers realize that

the efficient movement of material throughout the works is their responsibility; therefore, they cooperate in arranging the trucker's time for their mutual advantage. Whenever a dispatch clerk receives a call to haul material into another zone, he contacts the dispatcher in that zone and tries to arrange for a return load for his trucker, or else will line up the load as a return trip for a trucker from the other zone. Whenever possible, the dispatchers will have truckers leave material destined for another section at the dispatch station, knowing that it can be transferred there to another truck returning to its home station.

The dispatchers are depended upon for the efficient handling of transportation equipment. First, two of the dispatch offices were so located that the dispatchers were able to check most of the trucks coming into their territory. Afterwards, the third station was similarly located, and the dispatch offices were used also as transfer points. Trucks assigned to a station operate only within the zone, carrying outgoing loads to the station, where these loads are transferred to trailers and hauled away by the plant tractor-trailer system. A tractor usually pulls from ten to fifteen trailers.

There are times, of course, when it is more practical to dispense with the transferring and to deliver loads direct. In such instances, dispatchers arrange for return loads. The tractor-trailer system, as first set up, was limited to material being delivered from the receiving department only. The sections sometimes fell into the habit of using trailers for storage purposes, and an important element in the tractor-trailer set-up was to discourage and eliminate this practice. The industrial truck system has done an excellent job even under the overcrowded conditions which existed in the plant during wartime activities. By keeping in close contact with their dispatchers the truckers have minimized their empty traveling time, which is the best indicator of high efficiency.

Operation and Maintenance of Equipment

OPERATION.—It is important that materials handling equipment be properly operated and that the manufacturer of equipment such as bridge tramways, pneumatic conveyors, and plating conveyors send competent men to train the purchaser's employee or employees. Often equipment apparently fails, not because it has been wrongly selected or improperly designed or constructed, but from lack of intelligent operation. In the case of electric trucks, tractors, or other mobile equipment it is wise to give operators elementary training in driving them. Usually a few hours are sufficient to determine whether or not a man has the necessary qualifications for a safe and efficient operator. A test of sight, hearing, reflexes, and speed of coordination is usually desirable.

Physical plant conditions, particularly with respect to grades, is an important factor to be kept in mind in the operation of industrial trucks. Each 1% of up-grade requires 20 lb. additional tractive effort per ton. To haul a load up a 2% grade, therefore, requires double the power required on a good, level floor; and up a 10% grade, six times as much (Indus. Truck Stat. Assn., Materials Handling Handbook). These figures emphasize the desirability of avoiding operation on steep grades

as much as possible, although ramps are often preferable to elevators from the standpoint of delays.

MAINTENANCE.—Materials handling equipment is so diversified that it is frequently neglected in general plant maintenance inspection. This class of equipment is usually half-way between production equipment and fixed departmental equipment, and for this reason may not come directly under general factory inspection. Under such conditions it is essential that department heads definitely assign to certain operators the responsibility for the inspection. One of the most frequent abuses of this sort of equipment is improper or inadequate lubrication and failure to repair or replace worn parts. In particular, trucks should be cleaned and oiled, and batteries put on charge on a regularly established schedule.

No maintenance program is effective unless (a) the responsibility is fixed for a periodic check of each piece of equipment; (b) an appropriate method of reporting, by check list or otherwise, is applied; (c) immediate and effective action is taken on such reports; and (d) proper records are kept with respect to cost of maintenance. Failure to fix the responsibility has often resulted in neglect of the equipment, and unnecessarily high operating and repair costs.

If, under an **adequate program of maintenance,** a piece of equipment shows high maintenance cost, an examination should be made to see whether the cause is defective operation, overloading, or misapplication.

Proper care and maintenance of floors is an important item in operation of mobile equipment, particularly tractors and trailers. Smooth, level floors not properly maintained and allowed to grow rough and uneven will increase the tractive resistance as high as 30% with resulting loss in economy of operation. Fig. 43 shows tractive resistances for various kinds of running surfaces.

MATERIALS HANDLING HAZARDS.—When studying materials handling methods the safety aspects must be given consideration, particularly in methods involving manual handling. Better methods should result in fewer accidents as well as lower costs. The New York Department of Labor in its Bul. No. 181 says:

> In the whole field of industry, there is no place where safety and efficiency are so intimately associated. The same effort which makes handling of goods less costly also makes it safer.

Listed below are a few simple **rules to assist in reducing hazards.** Others which will apply to the particular work involved should be added. (See Safe Practices Pamphlet No. 55: National Safety Council, Inc., Chicago, 1940; and National Safety News, December, 1940.)

1. Mark or paint lines on the floor indicating aisles or truck runways.
2. Keep aisles clear of overhanging or projecting obstructions.
3. Provide adequate overhead lighting in aisles.
4. Place large mirrors at blind corners.
5. Keep all runway floors in good repair.
6. In case of wooden floors, use rubber-tired wheels on hand trucks.
7. Provide knuckle guards on handles of two-wheel trucks.
8. Install glass panels on doors in trucking aisles.
9. Remove defective trucks from service.

10. Train operator in safe way of doing his work.
11. Avoid overloading or loading too high.
12. Loads should be made secure to prevent falling.
13. Common hand trucks should be pushed, not pulled.
14. Loads on two-wheel hand trucks should be balanced over wheels.
15. Assign heavy tasks to individuals who meet physical requirements of the job.
16. Do not permit anyone to ride trucks.
17. Encourage use of safety shoes.

Investigating Economies of Materials Handling Equipment

SELECTION OF MATERIALS HANDLING EQUIPMENT.—Continuous process industries such as flour, sugar, cement, chemical, and steel are so organized and the nature of their products is such that it pays to use highly specialized equipment for handling work in process. Similar conditions exist in the repetitive-type industries making successive lots of almost identical products on a mass-production basis. Materials handling problems in a clothing factory, knitting mill, or jobbing machine shop, on the other hand, involve factors in the main very different from those in bulk industries and single-purpose equipment may not be economical.

While there are many special types of equipment available, it is usually wise to make direct application or adaptations of standard equipment, or combinations of standard equipment as manufactured by reliable companies, rather than attempt to design an installation for a particular purpose. This means broad familiarity with all types of tried and proven equipment. There are usually several ways of employing the different kinds of equipment that are available for a given solution of any problem.

Before a definite commitment is made on the purchase of any new equipment it is advisable to be sure that the maximum benefits are being attained from the existing equipment. Too often, new equipment has been purchased without sufficient study of the possibilities of that on hand.

The deciding factor should be lowest cost per unit of material handled. It is important also that the over-all handling problem be kept in mind when making such studies, for an economical method of handling at one stage may dictate the use of a less economical method at later stages.

Service and Performance.—A source of much subsequent trouble in the selection of materials handling equipment for a specific set of conditions is the confusion between actual service and mere mechanical or electrical performance. A device may be mechanically perfect, yet its selection for a given set of conditions for which it was not designed, will be an economic error. The application of common sense and a complete analysis of existing and proposed methods as well as a knowledge of the various types of equipment will generally bring about the proper selection of equipment for a specific set of conditions.

Reliability of Equipment.—Tried and proven materials handling equipment is as dependable in performance, and in freedom from break-

down, as productive equipment, provided the proper equipment has been selected for the conditions imposed. If breakdowns occur, or if maintenance is high, it is practically always due to lack of care, to improper selection of the units in the first place, or to overloading the equipment.

FORMULAS FOR COMPUTING ECONOMIES OF MATERIALS HANDLING EQUIPMENT.—It has been the practice to consider savings from materials handling equipment in terms of labor-saving only, but this is not the only factor to be given consideration. If handling has been done by manual means and mechanical appliances are being considered, it is necessary to take into consideration the human element, but it will be found that materials handling equipment as applied to new installations permits a higher output to be produced within the same, or even a smaller floor area, reduces accident hazards, permits absolute mechanical control, and frequently simplifies processing.

It is difficult to set up a definite economic formula for use which would apply to all installations and which would fully cover all the economies that can be made by use of materials handling equipment. In computing costs, labor to be saved is generally classed as indirect or nonproductive labor. Being thus a part of overhead charges it should not bear any superimposed charge from other components of overhead, as this would be pyramiding the charges. In calculating comparative cost, a new item is introduced which becomes a factor in regular cost accounting and which engineers and economists recognize, namely, monetary value of increased production.

With these considerations as a foundation, the formulas for calculating **economies of labor-saving equipment,** developed by the Materials Handling Division of the American Society of Mechanical Engineers, are:

Let A = Percentage allowance on investment
B = Percentage allowance to provide for insurance, taxes, etc.
C = Percentage allowance to provide for upkeep
$\frac{1}{h}$ = Percentage allowance to provide for depreciation and obsolescence, where h is the number of years estimated as the period of useful life of the equipment
E = Annual cost of power, supplies, and other items which are consumed, total in dollars
S = Annual saving in direct cost of labor, in dollars
T = Annual saving in fixed charges, operating charges, or overhead, in dollars
U = Annual saving or earning through increased production, in dollars
X = Percentage of year during which equipment will be employed
I = Initial cost of mechanical equipment

Then Z = Maximum investment, in dollars, justified by above consideration
Y = Annual cost of owning mechanical equipment in condition ready for operation
V = Annual profit from operation of mechanical equipment

Then

(1) Maximum investment $$Z = \frac{(S + T + U - E)\,X}{A + B + C + \frac{1}{h}}$$

(2) Annual cost of owning equipment $$Y = I\left(A + B + C + \frac{1}{h}\right)$$

(3) Annual profit $$V = [(S + T + U - E)\,X] - Y$$

As handling machinery, even if left idle a large part of each year, will probably require approximately the same repairs, due to deterioration, as though in use, no deduction is made for idleness in estimated cost of upkeep, C. If greater accuracy is necessary, use a value for C multiplied by X in place of C in the formulas.

APPLICATION OF FORMULAS.—For example:

Assume the handling of miscellaneous materials about a factory, formerly done by four men each receiving \$3.50 per day, and allowing 300 days operation, giving an annual direct cost of \$4,200, can be done by one man operating an electric storage battery industrial truck with a direct labor cost of \$1,050 per year, effecting a saving of \$3,150 per year in direct labor cost.

Assume also that through greater promptness in moving materials and more continuous operation of machines there is an increase in earnings due to increased production of \$650 per year. In actual practice the plant operates 240 days per year or 80% of the time.

The various factors, therefore, are estimated as follows:

A = 6% Interest on investment
B = 4% Insurance and taxes
C = 20% Upkeep
h = 4 years
$\frac{1}{h}$ = 25%

E = \$450 Power, supplies, etc.
S = \$3,150 Annual saving in labor
T = \$315 Saving in fixed charges, etc.
U = \$650 Increased production
X = 80% of year

$$Z = \frac{(\$3{,}150 + \$315 + \$650 - \$450) \times .80}{.55} = \$5{,}331$$

This indicates that equipment costing any sum below \$5,331 will earn some profit above interest on investment and maintenance.

Assume that an electric storage battery industrial truck will meet the conditions stated and that its cost will be \$2,200. Then the annual cost of owning equipment ready for operation will be expressed by the formula, $Y = I\left(A + B + C + \frac{1}{h}\right)$, or \$2,200 × .55 = \$1,210. Then profit from operation of mechanical equipment, V, according to (3), becomes [(\$3,150 + \$315 + \$650 − \$450) × .80] − \$1,210 = \$1,722. Profit, V, \$1,722 represents annual earning upon initial investment, over all items of cost, of over 78%.

The example above is for bulk handling of materials by power-driven industrial truck, where the equipment is operating under rough usage and heavy loads. In package-handling equipment the item C for upkeep would be in the neighborhood of 3% and item $1/h$ for depreciation due to wear and tear considerably less than shown here.

Further examples of the application of these formulas and the factors used are given in Fig. 58.

	Total cost incl. installation and auxiliary equipment	Annual labor saving	Per cent on investment	Per cent for insurance	Per cent for maintenance	Per cent for depreciation	Cost of power	Overhead annual saving	Replaced-equipment fixed charges	Value of increased production	New equipment fixed charges	Unamortized value less resale value	Maximum investment to return simple interest on investment	Yearly profit from operation	Yearly profit in per cent on investment	Years for complete amortization out of profits
	I	S	A	B	C	$1/h$	E	T_a*	T_b*	U	Y	K*	Z	V	P	X
Coal-handling and ash-handling system in heating plant	$ 1618	$ 600	6	2	10	10	$ 40	0	0	0	$ 453	0	$ 1928	$ 107	12 61	4 42
Battery truck in wire mill	2143	3200	6	2	20	17	70	0	0	0	964	0	6955	2164	106 98	0 807
Battery truck in rubber mill	5600	2400	6	2	20	17	100	0	0	0	2520	0	5111	220	2 07	5 24
Finished-stock room to shipping-room conveyor	1450	2400	6	2	8	10	50	0	0	0	377	0	9038	1973	142.07	0.657
Rubber finish to stock-room conveyor	1500	1800 Estimated	6	2	5	10	0	0	0	0	345	0	7826	1455	103.00	0.885
Label dept. conveyor	2000	4000 Estimated	6	2	8	10	10	0	0	0	520	0	15231	3440	183.00	0.518
Stock-room to shipping-room conveyor	2200	3000	6	2	5	10	0	0	0	0	506	0	13044	2494	119 66	0.771
R. R. cars to stores and finished stock to cars	3100	2400	6	2	10	10	100	0	0	0	863	0	8846	1432	52.19	1.61

NOTE: Factor X was taken at 100 per cent of full normal-time operation.

* These factors appear in the original formulas developed but are often taken at zero values, as here, so have been included in a general factor T in the abridged formulas and the example given in the present discussion.

FIG. 58. Condensed Statement of Factors in Materials Handling Formulas

SECTION 15

JOB ESTIMATING

CONTENTS

Estimating Foundry and Plating Materials

Estimating Nonmetallic Materials

Summaries of Job Costs

SECTION 15

JOB ESTIMATING

DEFINITION.—It is common practice to estimate in advance the cost of jobs or manufacturing orders to be put through. These estimates often form the basis for quotations on prospective orders, the awarding of the order being based in many cases on price. Job estimating is equally important in plants making products for stock. Costs are a determinant in selling prices, often, also, in a decision as to whether to quote on an order or to produce an item for stock. They are also the basis for financial control of manufacturing, and the starting point of a major portion of the undertakings in methods improvement, work simplification, quality control, purchase of improved equipment, and other technical matters.

Job estimating itself is somewhat broader than cost estimating, in that it is often concerned with equipment, methods, quantities of materials, times for operations, etc., from the physical standpoint. Materials must be estimated as a basis for purchasing. Times must be determined to set delivery date.

Job estimating, therefore, may be defined as follows:

> The process of compiling a statement of the quantities of materials required, the amounts of time involved in production, and the procedures to be followed in putting an order through, together with the cost of the articles made or to be made, where experience supplies no complete figures.

In compiling the above factors, use may be made of actual cost figures, past or present, and of facts concerning the available plant and equipment, labor and burden rates, present and future market prices of materials, knowledge of the processes to be performed, and times required, with good judgment applied to all these elements.

Scope of This Section.—This Section sets forth accepted practices and methods of estimating the physical factors and the cost involved in making mechanical products for the purpose of:

1. Setting sales prices.
2. Determining whether or not to manufacture a certain product.
3. Blocking out the major plan for the job.
4. Furnishing a basis for the cost control of manufacturing.

Construction work, large special orders such as for steamships, and the work of special processing industries are not covered here.

Cost estimates of the kind presented here are necessary to make sales proposals, to bid on new work offered, and as the basis for special contracts. The **work of estimating** involves engineering, production, and

cost knowledge and experience in addition to mature judgment. Good methods for estimating are vital. If an estimate is too low, money will be lost; if too high, work will not be undertaken or it will go to a competitor.

Estimates are of great value also as an aid in controlling costs in the various departments involved in producing a project after an order has been received. It is important that estimates be in sufficient detail and be issued promptly on receipt of an order so they can be used as a guide at the beginning of a project before it is too late to take corrective action.

FACTORS IN COST ESTIMATING.—The principal factors to be considered in all estimates of cost are:

1. Previous estimates.
2. Previous actual cost records.
3. Expected future rates of labor, material, and overhead.
4. Uses of building, machinery, tools, and equipment.
5. Quantities to be manufactured.
6. Time available for production.
7. Efficiency of available labor.
8. Competitive situation and possible repeat business.
9. Matured good judgment.

Previous Estimates.—Previous estimates of articles, or estimates which were made on similar products, should be used in making, or in checking, current estimates. A considerable amount of time may be saved in making use of previously estimated items or parts, which are component parts of the product on which an estimated cost is desired. Previous estimates are also useful in comparing and checking completed costs of the product as a whole, due consideration having been given to changes in labor rates, material costs, plant equipment, and layout.

Previous Actual Cost Records.—The cost records are the actual records of costs of products already made. They may contain a record of the article to be estimated or reestimated, or the cost of similar products. They may also contain the cost of various units or component parts which can be used in the estimate.

When using cost records for estimating, consideration must be given to factors such as excess spoilage, expense of repairs or reoperations, and inadequate layout of equipment which may have affected the previous costs and which should be eliminated in computing the current cost estimate. The cost estimator, when using cost records for estimating for the purpose of fixing prices, should be careful to see that such records reflect a true cost based on quantities which are now expected to be sold. They may be available on first runs of product, for which production no special tools, jigs, dies, or fixtures were made, but which were made with tools and equipment used on other jobs. Use of these tools, dies, jigs, fixtures, and equipment intended for other purposes may have caused a greater labor cost than if the manufacturer had available special tools and equipment built especially for the job.

The same situation holds with repairs or reoperating of products shown on the cost records. Perhaps the cost records show the cost of the runs during which time the employees or operators were inexperienced and produced, as compared with normal operations, an excess

of bad pieces which required excessive repair or reoperations. The materials used likewise may not have been the most suitable for the jobs. Perhaps, also, the first product was produced with machinery and equipment not especially designed or laid out for larger or continuous runs of the product to be estimated. This condition may have caused additional handling or other increases in cost which could be overcome if the machinery and equipment were especially planned for the production of the article, the cost of which is being estimated. When using cost records for estimating purposes, all of these factors should be carefully considered as they may be more or less modified or changed if longer and continuous runs are expected to be made.

Expected Future Rates of Labor, Material, and Overhead.—It is an accepted practice when estimating costs of products, as well as in actually costing the product, to divide the cost into three main divisions: (1) labor, (2) material, and (3) overhead.

Consideration should be given to the expected future costs of labor, material, and overhead, when compiling correct estimates. This factor is important in labor markets that are subject to violent fluctuations and during periods when material prices are subject to frequent changes. The overhead factor is subject to adjustments at all times due to changes in the organization of personnel, use of expense materials, and changes in use of machinery, tools, and equipment. The cost estimator may avail himself of information as to expected future cost of labor by keeping in close touch with the labor market reflected in current trade publications, information made available through trade associations, and through consultation with the manufacturer's own personnel department. The expected future prices or cost trends of material are always available to the cost estimator through trade journals, statistical reporting services, newspapers, and the manufacturer's own purchasing department. Overhead rates used in estimating may be subject to future changes if, for example, the article on which the estimate is to be calculated is expected to be produced in large quantities, and may be produced in separate or isolated parts of the plant, perhaps requiring less lighting, heating, power expense, indirect labor, machinery, tools, and equipment than if produced in smaller quantities or in departments where other merchandise is manufactured.

Use of Building, Machinery, Tools, and Equipment.—Careful consideration should be given to the use which is made of the manufacturer's buildings, machinery, tools, and equipment, or the expected use of these assets, in the manufacture of the product on which a cost estimate is to be computed. Cost of a product may be affected by the **use of buildings,** depending upon the layout and location of the building as regards the main plant, location of the main plant as regards the central warehouse, transportation facilities to and from one building as compared with another, and maintenance cost of one building as compared with another. The cost estimate may be affected by the **use of different machines.** An automatic machine, requiring expensive upkeep and a large amount of insurance and depreciation, taxes, etc., may be used to reduce the labor costs; or single-purpose machines may be used, thus reducing maintenance, depreciation, insurance, and tax costs, but increasing the labor cost. These comparisons must be made and deter-

mined upon as to which is the cheaper or better. **Use of tools, dies, jigs, and equipment** must also be considered in the same manner as use of machinery. It may be possible to build a tool to reduce the labor cost, but the cost of the tool may more than offset the labor which may be saved.

Quantities to be manufactured must also be taken into consideration because on small runs the cost of special tools may increase total costs beyond the present market or selling price. The possibilities of repeat orders should always be counted upon but not relied upon in spreading the cost of special tools, machines, buildings, etc., when estimating costs. Here again, time is a factor. To produce an article within a given time it may be necessary to make additional special tools, dies, and jigs in order to satisfy a customer, and these costs should also be included in the cost estimate.

Time Available for Production.—Time available for production is an important factor which must be taken into account in all cost estimates. By time available is meant the time for the production of quantities of the product to be made. If the customer desires, for example, to purchase a product, one unit to be delivered each day for, say, a month, while another customer may wish deliveries to be made two per day over the following 15 days, the estimated cost may be materially affected. It may be necessary, on account of the limited time for the production of the articles, that bonus, premiums, or overtime be paid. Cost of building, machinery, tools, and equipment may be affected by the time element if additional or new buildings, machinery, tools, and equipment are necessary in order to get the work out on time.

Efficiency of Available Labor.—The cost estimator should always be conscious of the fact that during periods when labor demand exceeds the supply, a lower efficiency must be anticipated than exists when conditions are normal or when labor is plentiful.

Competitive Situation and Possible Repeat Business.—In entering a new field of endeavor, it is advisable to make a survey of competitors already in the business, equipped and tooled for manufacture, and also the possible available business in the field being entered. A knowledge of these facts is important for the following reasons:

1. The cost of capitalized equipment is written off as an item of overhead expense over a period of years; therefore, it is necessary to know something of the potentialities of the project in order to determine the justifiable expenditure.
2. Fixed charges such as engineering, tools, and plant rearrangement are either charged directly to an order or amortized in the selling price of the article. To establish a competitive selling price it is often necessary to amortize only part of the fixed charges through the particular article or order or apply only a relatively low margin of profit on the original order.

Matured Good Judgment.—Another, although more elusive, factor in cost estimating, the importance of which must not be overlooked, is that of matured good judgment. By matured good judgment is meant the innate faculty a cost estimator may have, growing out of his experience, which enables him to estimate the cost of a product or its component parts, without the use of special data. Briefly, having matured good judgment is being endowed with a practical sense of values.

DETERMINING WHETHER OR NOT TO MANUFACTURE A PART OR PRODUCT.—It does not always pay to make a proposed product. Many manufacturers do not quote on proposals outside of their fields, or beyond the range of sizes which they usually make, because they find no profit in such ventures. For the same reason, many plants do not produce certain of the parts used in their finished products. Outside companies make many such parts at lower cost. The following analysis may be applied to such cases.

If the proposed item is a component part of the company's product:

1. Estimate the total actual cost.
2. Find the purchase price from an outside company.
3. Determine whether there is sufficient profit, either in dollars saved or in time, to warrant manufacture of the part.

If the item is a new product for the company, with no competition:

1. Make a market analysis to estimate the total quantity which may be sold.
2. Analyze the market to determine the approximate selling price.
3. Make a cost estimate.
4. Determine if the difference between the possible selling price and the cost estimate gives sufficient margin for profit.

If the item is a new product for the company, with competition already on the market:

1. Determine by market analysis what the company's share might be.
2. Make a cost estimate of the total quantity to be sold to this market.
3. Ascertain the present market selling price.
4. Determine if the difference between the possible selling price and the cost estimate gives sufficient margin for profit.

Job Estimating Department

LOCATION.—Companies differ greatly in the methods under which they set up job estimating. As in other plant activities, no set rule can be laid down stating where such work should be carried on. Each case must be decided according to the conditions and problems which enter into it. Occasionally the estimating department is connected with the sales department, but such a practice is not recommended where there is any considerable degree of engineering, or operating information required of the job estimator.

Engineering and Operating Departments Doing Job Estimating.—In smaller companies, the estimating is sometimes done in the engineering, sometimes in the manufacturing, department, each reporting to the general manager or factory manager. Where men in these departments have a close and detailed knowledge of the products made and equipment, processes and methods, materials, and kinds of labor used in the plant, and the times and relative costs of the jobs which are put through, the results secured under this plan, even in competitive markets, are not far from the average actual performances and costs. Such men know that they must later bring about accomplishments in line with their estimates and therefore are realistic in their statements and judgments in estimating. Such companies, moreover, may not see their way

clear to set up organized cost and estimating departments, but they do keep certain records and make certain analyses to prevent getting too far out of line. It is obvious that in companies making products to special order, both engineering and operating men must be associated in the job estimating.

Estimating by Cost Department.—In larger companies, cost departments are usually organized and provisions for accumulating and analyzing costs on jobs are set up as a basis of financial control. These cost departments usually report to the controller or treasurer. Sometimes such cost departments handle job estimating, having records of previous job costs to go by and therefore being in a position to assemble representative figures from actual performance. For jobs of a highly repetitive nature, such a plan is satisfactory. The cost estimator naturally will be kept in touch with significant changes in materials costs and labor rates from the current materials requisitions and time tickets collected for cost determination. Changes in overhead rates will also be called to his attention because he must have such data to compile costs correctly on current jobs.

The engineering, methods, and materials factors, however, may be changed from time to time on jobs to go through, even when these jobs are repetitive, and especially if production in larger volume is to be undertaken. Designs of parts and assemblies may be altered, or different materials may be used, so that the data from previous work will no longer be accurate or even representative. Greater production may mean the use of automatic machines instead of single-purpose machines and thereby change both methods and labor rates on the work. Rearrangements of equipment may modify overhead charges because of greater convenience, reduced handling, and quicker production. Unless such factors are known to the cost estimator, or unless his figures are checked in detail by someone in touch with engineering and design, plant layout and methods, and materials and materials markets, the job estimates may be considerably out of line with the facts in the case. In many cases, moreover, the prospect of incoming orders may lead to changes in design, methods, equipment, and layout for doing and handling such work at lower costs. An estimate resulting in quotations to prospective customers on the former basis may shut off orders that could be very profitably handled after such changes were introduced.

Job Estimating Department.—For better results than can be secured under the above methods, a job estimating department or section is sometimes set up. It may report then to the general manager or factory manager. A plan of this kind is especially necessary where large special jobs are undertaken involving considerable engineering, design, and planning, and where special attention must be given to the factors of layout, equipment, tooling, methods, labor control, production control, and other operating factors and facilities. Whatever data are needed on the history and costs of previous jobs, or on parts of such jobs which were similar, or bore a close resemblance, to corresponding elements in the proposed job, can be obtained from the cost department. Job estimators, familiar with engineering, design, materials, and plant operating factors, and knowing the right persons to go to in the engineering, purchasing, production control, and operating departments to

obtain information and advice as to set-ups and procedures for the proposed new work, can assemble all the required information and calculate and compile the data for design and procedures and corresponding labor, material, and overhead costs on the work.

There are, moreover, many long, detailed calculations to carry out in making the estimates, and in many of these some knowledge of the technical processes, characteristics and properties of materials, machines and tools required, labor operations involved, combinations of operations possible, and output attainable, is of decided help even if such facts can be obtained from the operating departments. These latter departments are organized to turn out work and only incidentally to give repeated information on processing details, especially to estimators not too well trained for their work. In later paragraphs on raw materials estimating, some of the calculations and samples of the references and tabulations which must frequently be consulted will indicate why job estimators need some familiarity with technical and operating matters.

In many lines of industry the best results are obtained when the estimating department reports to an officer of the company who has the over-all viewpoint of both selling and manufacturing. This impartial viewpoint enables the executive to obtain unbiased results in developing estimates.

Job Estimating Associated with Production Control.—Growing attention is being given to associating job estimating with production control, although in a separate section of the latter department. This plan is logical and has many elements to recommend it. The production control department, through its various sections, plans and directs the dispatching of all jobs going through production. It originates the forms —materials requisitions, time tickets, etc.—upon which cost data on jobs are collected and sent to the cost department. It has a section dealing with materials, and must determine from engineering drawings, specifications, and bills of material the kinds and quantities of materials and the kinds and amounts of parts needed for the job. These figures include allowances for waste and spoilage. Methods engineering is carried on to determine equipment, tools, and processes, and the time study and rate-setting sections have, or determine, labor data, from all of which operation lists are prepared. The remaining sections of this department contribute other factors. Through its dispatching section the department is in touch with all operating departments and has close contact with all work. The production control department, in addition, actually plans, schedules, and controls the progress of all jobs going through. Therefore, it is in a position to include a section on job estimating as a separate function, but kept in touch with all the necessary sources of reliable, up-to-date estimating information—even plans for changes. Likewise, since it plans work it is responsible for correctness in its planning and for seeing that plans laid down are carried out. Actual performance and actual costs, therefore, would seem more likely to approach close to job estimates under this arrangement than under any of the others.

ORGANIZATION.—The principal functions performed by a job estimating department are as follows:

1. Estimating for the purpose of setting sales prices.
2. Estimating for setting standards for accounting purposes.
3. Estimating for the purpose of determining whether or not to engage in certain kinds of business.
4. Estimates to forecast programs of production and costs on orders so that control may be based on such estimates.

The job estimating department, in many cases, is also the price fixing department. The price fixing function is not a function which depends entirely on figures prepared by the cost estimating department, as modifications may have to be made to conform with general economic conditions, market conditions, competition, financial structure of the company doing the selling, together with the speculative factor of what all of these conditions may be in the future.

S. C. Horst, of the Edward G. Budd Manufacturing Co., offers the following suggestions on practical points in organizing an estimating department:

1. It is good practice to establish specialized groups if there is a wide variety of work to be estimated. Some examples of specialized groups are:

a. Tools, equipment, and machine-shop work.
b. High-production manufacturing.
c. Low-production (job-shop work) manufacturing.

2. It is advisable, however, gradually to rotate the estimators from one group to another to develop an efficient department which is flexible enough to handle a temporary overload in any phase of the work. When new department supervisors are to be appointed, they should be selected from the men who have shown special ability in the course of obtaining this all-round experience.

3. The work in compiling an estimate can be advantageously divided to a certain extent between estimating and calculating. The calculating can be done by girls just as efficiently and rapidly as by men.

4. The record and filing system in an estimating department is of considerable importance. Cross-reference and index systems should be kept so that any estimate may be quickly located if the customer, or description, or project number is known.

5. All estimates should have all calculations checked after typing. This plan gives a double check on both calculating and typing.

6. In describing the functions of an estimating department, it is necessary also to outline the related functions of other departments involved in the estimating process. The proper organization and functions of the various departments vary with the nature of the business. The following outline presupposes an organization set up to handle projects requiring considerable engineering and planning.

Sales Department: Issue a request for the estimate and outline the project, giving the following information:

1. General description of project including use or type of service.
2. Potentialities of this kind of business.
3. Competitive situation.
4. Required date when delivery should begin and the rate at which production should be carried on.

Engineering Department (Proposal Group): Develop design and specifications and send copies to purchasing, tool, methods, and equipment.

Purchasing Department: Purchasing engineer or buyer secures competitive prices on material and equipment purchased outside and forwards this information to the estimating department.

Planning Department (Schedule Section): Establish delivery starting date and rate, and forward this information to the estimating department.

Estimating Department: The estimator checks the following information received from other departments and adjusts it in consultation with other departments involved to form an organized program of procedure:

1. Engineering design and specifications.
2. Manufacturing methods and procedures.
3. Tools and equipment.
4. Plant rearrangement.
5. Prices on materials and equipment purchased outside.

The estimator prices the complete project considering the following elements:

1. Experimental and development cost, including testing.
2. Engineering design cost.
3. Tool, equipment, and pattern cost.
4. Plant rearrangement.
5. Material (raw material and items purchased outside).
6. Labor.
7. Overhead.
8. Crating and loading cost.
9. Transportation cost.
10. Profit.

Estimates are checked by the department supervisor and submitted to the management for approval. After approval, all estimates are typed and all calculations checked with the comptometer and the estimate is then forwarded to the sales department. When an order is received, the estimating department releases the details of the estimate to all departments concerned, to be used for cost control purposes.

In some organizations, the purchasing engineer and the process engineers who do proposal work are part of the estimating department. The advantages of this arrangement are that projects are priced more expeditiously and at a lower cost. The disadvantages are that when people doing this work are removed from the purchasing and production departments, they lose a certain amount of contact with the actual manufacturing problems and may not always be up to date on the latest developments.

KINDS OF KNOWLEDGE REQUIRED OF ESTIMATORS.—The experience of the personnel of the job estimating department should include both general and cost accounting experience, some engineering training, the ability to read blueprints, shop experience if possible, and thorough knowledge of shop layout and equipment, also the ability to keep abreast of economic conditions which are constantly changing.

Cost Accounting.—The job estimator requires a knowledge of cost accounting so that he may be able to read cost analysis sheets and cost

statements, and to make proper deductions therefrom in using these records for estimating costs. He requires a knowledge of general accounting to enable him properly to determine the relative overhead charges which prevail at the time of making the estimates. He must know why overhead rates are going up or down, and must also know the relation of overhead rates to general production, increases of cost of material and labor, and how to assign relative values to these items and determine what figures will be used in his estimates.

Engineering.—The estimator must have some engineering ability because he is constantly confronted with problems of estimating on products which have not been previously manufactured and on which regular engineering time cannot be spent. This work refers to simple engineering problems, and not to those involving stresses and strains, electrical characteristics, chemical analysis, etc. The job estimator's engineering ability should enable him to determine whether or not further engineering work is necessary before proceeding with the estimate.

Plant Layout and Manufacturing Methods.—One of the necessary qualities of an estimator is a thorough knowledge of the plant layout, production methods, and machinery and tools available. If a new product comes in for estimating, he should know in all ordinary cases where the product will be made, what processes will be necessary for its manufacture, what price labor will be used, kinds of material which will be worked upon, and what machines and tools are available for its production. He should have a knowledge of tools and equipment on hand so as to guard against estimating on new tools where old ones may be usable. He should know the production capacity of the plant so that he can determine whether or not the time allowed for production is sufficient. He should also keep in touch with the current production so as to determine if space is available in case the order is received, and whether it may be necessary to install new equipment or work overtime.

Shop Experience.—On work of a complicated nature, requiring considerable engineering and planning, one of the most important requirements for an estimator is that he have a certain amount of actual experience of doing productive work in the shop. The actual experience of working in the shop gives a background for developing judgment in connection with figuring labor costs which is difficult to acquire any other way. There are exceptional cases, however, where men who have not had actual shop experience have become successful estimators. They have overcome this disadvantage by a considerable amount of observation in the shop during their period of training to become an estimator.

Economic Conditions.—If the estimator sets the prices, he must keep in touch with the general economic condition so as to determine in his own mind whether or not commodity prices may be expected to increase or decrease, whether labor prices may be expected to rise or fall, whether or not the market will absorb a large or small quantity, whether greater sales effort and expenses are necessary for the distribution of the article to be priced, and determine in advance how much profit may be expected over certain periods of time from the sale of the article at either low, medium, or high prices.

Contacts Outside of Department.—In the organization of a job estimating department requiring several employees, it may be feasible to employ subordinates who are specialists in various lines of production or specialists in the functions previously mentioned, such as a man familiar with general and cost accounting, an engineer and draftsman, a production man, and a subordinate staff for clerical, stenographic, and filing work.

There are times when it becomes necessary for the estimator to go outside his own department in order to confirm his own knowledge of sales conditions, financial conditions, and production facilities. In these cases, and in every case where there is a doubt, he should consult with the sales, production, and financial departments, especially where the business at stake may be of considerable volume. The job estimating department should supply prices for catalog price sheets and quotations on special work which are to be used by the sales department when contacting customers.

The estimator should at all times keep in close touch with all sales activities and the sales department should keep him informed as to changes in sales policies and market conditions. The sales department is the first to come into contact with competitive merchandise and competitive prices and should transmit any information as to changes affecting merchandise and prices quickly to the estimating department. The estimating department, on the other hand, should seek through its contact with the sales department, and through the medium of trade journals and newspapers, for facts that may have any bearing on the merchandise or on changes in current market prices.

The cost estimator must consult with the tool designer or master mechanic in all cases which involve the making of new tools or reconditioning of old tools for new uses. As a general rule, it cannot be expected that an estimator be thoroughly competent to design tools and to estimate their cost, neither is it economical in general practice, especially when most manufacturers of mechanical products have their own tool designer or toolmakers. While the estimator should have a thorough knowledge of the plant layout, available machinery and equipment, he cannot be expected to know as much as the production or manufacturing departments know about them. He should consult, therefore, with the production department on all new merchandise in order to determine what equipment will be used in its manufacture, what class of labor will be used as operators, and what production may be expected within certain periods of time. The information that the time study and the rate-setting sections of the production control have available is very useful in estimating and in case the estimator is confronted with a problem outside of his own knowledge or experience he can avail himself of the experience of these sections.

It is necessary that the job estimator consult with the cost department, or have available the cost department records of previous costs of articles to be produced, or similar articles, and also the records of units or component parts of the product to be estimated, or similar products. He should also keep in close touch with the general trends of the costs of labor, material, and burden as reflected in the information available in the cost department.

Elements of a Job Estimate

OPERATING AND COST DATA REQUIRED.—In building up a job estimate there are a number of elements covering operating and cost data which must be considered and on which data must be assembled. The elements comprise, in the main, the following kinds of information:

1. Design time.
2. Drafting time.
3. Methods studies, time studies, planning and production control time.
4. Design and procurement or manufacture of special patterns, core boxes, flasks, tools, dies, jigs, fixtures, etc.
5. Experimental work required.
6. Labor.
7. Materials.
8. Overhead.

DESIGN TIME.—The amount and cost of time spent in designing mechanical products may be estimated on the basis of similar jobs previously manufactured or on the basis of the good judgment of the designer as to how much time will be required to design the product. On new and complicated products the job estimator will do well to consult the designer frequently, as design time may become a large and costly item to be considered in the estimated cost. The cost of whatever design time is spent in developing preliminary sketches, assembly layouts, specifications, bills of material, etc., as a basis for making the estimate will, of course, be known.

Estimates are sometimes made to quote prices on work for which contracts or orders may not be secured, but on which designing and drafting time has been spent. The costs of such time must be absorbed by the orders actually received and would be charged out in the overhead rates of such departments.

In the calculation of designing time, it is preferable that standard rates per hour be used to cover the cost of designers' time, and that no attempt be made to use the actual rates which are usually paid on a monthly or salary basis. If several kinds of designers are used in designing new products, they may be classified into groups and standard time rates be fixed per hour for each group, which standard rates may be used in calculating cost estimates.

Sometimes included in the design of products such as automobiles, airplanes, etc., is mock-up, or a dummy full-sized model of the proposed product. Such a model, with the numerous alterations usually made in the course of its development, takes considerable time to make and involves a high cost, both of which elements must be taken into account by the job estimator.

DRAFTING TIME.—Practically all mechanical products require drawings for the use of factory workers. The time and cost of drafting work on a new product may be estimated by an experienced draftsman on basis of his experience, after he has analyzed the product as to its component parts and the probable time required for making the drawing. For the purpose of calculating the estimated cost of drafting time,

it is recommended that standard rates per hour be established for draftsmen who may be paid on a monthly or yearly salary basis. These standard rates can be made so that they will be substantially the same as if the more laborious method of calculating actual rates were used.

METHODS AND TIME STUDIES, PLANNING AND PRODUCTION CONTROL TIME.—Before a job can be put through the plant, after the engineering work has been done, first the materials situation will have to be investigated and purchase requisitions placed for any needed materials not on hand. Then the manner of processing the job must be planned. For repetitive or routine jobs this work will have already been done and will be on record, but for new jobs it will be necessary to break the order down into its elements and for each part and subassembly, and for final assembly, to plan the kind and sequence of operations. Times must then be set on the various operations, after which schedules for doing the work will have to be set. All this work takes time, which must be taken into account in the job estimate, both as to its effect on delivery date, and its cost. Sometimes a percentage charge can be applied, but on special orders which consume a considerable amount of time a special calculation may be advisable. Dispatching work done by the production control department overlaps manufacturing time, but is an element of cost in production control operations.

SPECIAL PATTERNS, CORE BOXES, FLASKS, TOOLS, DIES, JIGS, FIXTURES, ETC.—When special facilities are required in the foundry, machine or processing departments, or assembly departments for the manufacture of a product, the cost estimator must be careful to include the time required and the cost of these items in his calculation of the probable manufacturing cycle time and cost of the product. The quantity to be made or sold must be divided into the cost of special tools, dies, jigs, etc., so that a proportionate share of the expenditure for these items may be recovered in the price of the article sold. Care should be taken to include not only the cost of special tools, etc., but also the cost of their upkeep during the time the product is being produced. On the other hand, the **possibility of repeat orders on the product estimated** should receive consideration in spreading the cost of these items. But not too much reliance should be placed on this possibility.

When estimating these costs it is well for the job estimator to consult with the tool designer, toolmaker, patternmaker, and others, because the estimating of such items requires, in most cases, a knowledge of the subject gained only through experience. All ordinary tools, dies, jigs, fixtures, patterns, etc., on which the estimator has previously calculated the cost, or which are required for only simple operations, may be safely estimated by him without any assistance.

EXPERIMENTAL WORK.—The time and cost of experimental work can be estimated only on the judgment of the cost estimator, designer, or engineer. When estimating the cost of new kinds of products, especially new inventions which have not been previously produced and which are usually in a rather undeveloped stage, the estimator must be careful in making reasonable allowances for the experimental work which is usually required. The main points to be considered in estimat-

ing the experimental cost of new articles are the equipment, labor, material, and time required to conduct the experiment. The experiment may be conducted with standard or special equipment. If standard equipment is to be used, the depreciation and the repair cost to put it back in as good a condition as before the experiment was started, should be included as a part of the cost. It may be necessary to build special equipment and its entire cost may become a part of the cost of the experiment. On the other hand, certain parts may be salvaged, and in such a case due allowance should be given to the value of the parts recovered.

In conducting experiments it is sometimes necessary to use materials or products which, after use, may become worthless. The estimator must estimate how much material will be consumed during the course of the experiment and take into consideration any salvage therefrom. He must also determine what class of employees will be used in making the experiment. In some cases the services of highly trained mechanical, electrical, and chemical engineers may be required; in others, only the services of workers may be needed. In either case due allowance must be made for the supervision of the persons carrying out the experiment. In estimating the labor required, due allowance should also be made for other factors that may affect the cost, such as expenses required to conduct the experiment under certain geographical or atmospheric conditions.

LABOR.—Estimating the cost of labor on mechanical products, as a general rule, involves more computations than that of estimating the cost of material and overhead. The job estimator must have a knowledge of the operations which will be performed, tools that will be used, machines that will be employed, and departments in which the product will be manufactured. He must also know the wage rates paid to workers on the different operations. These operations should be written down in sequence and in detail on specially prepared sheets. If the article to be manufactured is composed of various minor assemblies, each one of the minor assemblies should be broken down into its component parts and the labor operations on the parts should be listed in detail.

Fig. 1 is a detailed labor cost estimate of a center bracket formed from steel plate. It shows the estimate number, date the estimate was made, name of the customer, part number, drawing number, and a short description of the piece and material required. Under the heading "Department" are shown the department numbers in which the operations will be performed. In the next two columns are shown the name and number of the operations and the machines which will be used. These operations are listed in the sequence in which they will be performed.

Set-Up Time and Cost.—A section of this form shows the set-up cost detailed as to set-up hours, rate paid per hour, and cost of each set-up operation, with a subtotal of the set-up costs in each department. These subtotals are made for the purpose of facilitating the application of overhead, rates of which may, or may not, differ in the departments where the set-up work is done. In estimating set-up time, the estimator should have available in his files standard set-up costs on all ordinary products. In extraordinary cases, or where he is in doubt, he should consult with the production control or the operating department in making the set-up cost estimate.

DETAILED LABOR COST ESTIMATE DATE JAN 1, 19- NO. 12345

CUSTOMER MECHANICAL PRODUCTS COMPANY PART NO 6789 DRWG NO. 6613

DESCRIPTION CENTER BRACKET MATERIAL 1/8 x 5" C R STEEL STRIP 20' LONG

DEPT	OPERATION NO	OPERATION AND MACHINE	SETUP COST				OPERATING LABOR				OVERHEAD		
			SETUP HRS	RATE	COST	SUB TOTALS BY DEPTS	OUTPUT	RATE	COST PER M	SUB-TOTALS BY DEPTS	RATE %	ON SETUP LABOR	ON OPERATING LABOR
20	16241	SETUP NIAGARA 462	1/2	.60	30								
20	16081	SHEAR TO LENGTH "					3000	60	20				
20	16242	SETUP #4 BLISS PRESS	2/3	60	40								
20	11571	PERFORATE & BLANK "					1100	55	50				
20	16243	SETUP "	1	60	60								
20	12951	FORM "				1 30	450	55	1 22	1 92	175	2 28	3 36
18	14351	TAP TAP WHEEL					900	54	60				
18	16244	SETUP PLAIN MILL	1/2	.60	30								
18	14661	MILL SLOTS "					100	60	6 00				
18	15541	FILE BURRS HAND FILE				30	95	60	6 32	12 92	150	45	19 38
07	16245	SETUP SPEED LATHE	1/4	60	15								
07	11542	BURR 6 SLOTS (END MILL) "					600	54	90				
07	16246	SETUP MULTPL DRILL	1/2	60	30		900	54	60				
07	11941	CT SINK 2 HOLES "											
07	16247	SETUP TAPPING MACH	1/2	.60	30								
07	16561	TAP 2 HOLES " "				75	400	45	1 08	2 58	125	94	3 23
19	15151	DULL NICKEL PLATE					1000	65	65	65	100		65
QUANTITY REQUIRED 500					TOTALS	2 35				18 07		3 67	26 62
COST OF SETUP TIME PER M PARTS ON BASIS OF 500 PARTS						4 70						7 34	

ESTIMATED BY ____________

FIG. 1. Detailed Labor Cost Estimate

The set-up cost is separated from the regular operating labor cost so that the total set-up time may be calculated on the basis of the number of pieces to be made on the order. The regular operating labor cost per thousand will remain constant no matter how many pieces are made. Total cost of the set-up time represents the cost for the entire lot of pieces made.

Operating Time and Cost.—The next section of the detailed labor cost estimate sheet (Fig. 1) shows the cost of operating labor and the output on which the estimate of labor cost is based. Here are given the rates paid for the different labor operations and the costs per thousand pieces. Subtotals are provided for the total labor in each department so that the overhead rates can be easily applied. If the overhead is applied on an hourly basis, the number of hours instead of the amount of money should be totaled by departments. The next part of the report shows the estimated cost of overhead. In Fig. 1 the overhead is estimated on the basis of labor cost. While this basis is the most common, it is not the only one, nor necessarily the best one, which may be used. It is shown here for the purpose of explaining the cost estimating routine.

MATERIALS.—The estimating of materials involves extensive calculations of quantities to provide, including allowances for wastes in cutting, punching, turning, etc., and for spoilage in processing. The use of alternate or substitute materials may also be a factor considered. After these calculations are completed, often with the aid of data tables on weights, allowances, etc., the costs may be figured out with the aid of prices obtained from the purchasing or stores records departments. The materials factor is analyzed in detail in a later portion of this Section.

OVERHEAD.—Reference to overhead costs has already been made under the heading of "Labor," above, these costs covering all expenditures except those for labor and materials going directly into the finished product. A further discussion follows at the end of this Section.

Fundamentals of Raw Materials Estimating

MATERIALS PLANNING AND SUPPLY.—Proper planning and adequate supply of raw materials in manufacturing are most important factors in effective operation. The estimating of raw materials quantities is of such importance, however, and the technique of estimating is so highly developed, that special attention is here devoted to these phases of the subject.

The term "material" is used, throughout this Section, in a relative sense, for any article which is a finished product of one establishment may be the raw material of another.

The methods given are a guide in planning and estimating materials for machine and manufactured parts, such as are common in the production of small machinery, electrical equipment, and the like. The term "materials estimating" is used in the sense of determining quantities, which can be translated into costs through multiplication by unit prices.

LOSS THROUGH INEXACT MATERIALS ESTIMATING.—Direct losses and increases in cost flow from inexact materials estimating in manufacturing. If too much material is supplied on a manufacturing order, or for a manufacturing lot, there will be a loss through leftover materials which have been charged, through more materials handling to bring the unused materials back to the storeroom, through more record-keeping in inventory control, or through an excess of scrap. If too little material is supplied, the number of pieces made will not satisfy the order, thus requiring a new issue of materials or even a new set-up with an increase in cost. The introduction of labor-saving methods tends to decrease the importance of the labor element in manufacturing cost. This labor cost range is from 20% to 30% of manufacturing cost. Conversely, the importance of materials as an element in cost is increased. This material cost ranges normally from 30% to 55% of manufacturing cost. It may extend from about 20% to 90%. Wastes through poor estimating are strictly a matter of cost. Responsibility for material wastes rests, first, with the designing engineer; second, with the materials estimator; and third, with factory executives who determine manufacturing methods. Scrapped materials or parts resulting from any neglect of responsibility have little salvage value.

McKnight (Mgt. Eng., vol. 54) stated that the common attitude toward scrapped materials has been that they have little more, if any, value than sufficient to cover the expense of collecting, segregating, and transporting them. "The average salvage department, using its best efforts, obtains a return from the sale of waste product equivalent to 2% of the value of the factory output of finished product, and this is the accepted measure of the importance of the waste problem." To show what this materials waste may be, McKnight analyzed the incoming and outgoing freight in 10 representative plants and found the following average results:

Annual incoming productive material		78,000 net tons
Annual outgoing finished product		62,000 net tons
Difference		16,000 net tons
Difference as above (total waste)	16,000 net tons	
Scrap shipped	12,500 net tons	
Unaccounted for in shipments*	3,500 net tons	
Ratio of total waste to incoming materials		20%
Value of productive material purchased		$10,000,000
Average material shrinkage of 20%	$2,000,000	
Scrap sales	400,000	
Net loss (16%)	$1,600,000	

* Waste unaccounted for was delivered to dump, incinerator, or sewer.

Opposed to this net loss of 16% is the statement of J. K. Olsen to the effect that on 90% to 95% of ordinary jobs in metal-working shops scrap loss need be no more than 5%.

Losses Defined.—The nature of materials losses will be more clearly understood from the following definitions.

Scrap: The chips, short ends, spoiled parts which cannot be salvaged, but which can be sold for their material value.

Waste: Such material which cannot be accounted for, being lost in the

processing (burned up, run into the sewer, dropped on the foundry floor, etc.).

Spoilage: Material which with another operation can be saved as a finished part or product; sometimes called salvage (a bent part to be straightened, a crack welded, etc.).

NATURE OF RAW MATERIALS ESTIMATING.—Raw materials estimating should be the result of a careful and complete survey of the products to be manufactured. The purpose of the method of estimating is to insure the supply of a sufficient amount of material for an order or lot, and no more. All the factors which may produce a shortage in some extreme case should be taken into consideration in order that the estimate may be safe and not excessive. An excessive estimate will result in an overstock of raw material left on hand after running the required number of parts and thus increase proportionately the cost of each piece. The ideal raw materials estimate, then, is one which is so accurately balanced that it will insure a sufficient amount of stock for the required number of parts with a minimum of excess material at the end of the run. Where such estimating prevails, the cost of products is never out of proportion to materials charges. In making such estimates good judgment is necessary in determining allowance for various factors, such as variations in weight due to variations in thickness and composition, and others concerned with the product, manufacturing equipment, and methods of materials handling.

As an example, in estimating rod stock for screw-machine work, it is difficult to determine in advance the number of pieces which will be scrapped before the machine is set accurately to turn out satisfactory work. Several lengths of rod may be used up during the set-up process. In producing bent rod parts several lengths of stock also may be scrapped before tools are finally set. In using any kind of rod stock, there are short end pieces which are classed as waste or scrap. In producing stamped or punched parts there is usually a proportion of each sheet or strip which is unusable and therefore becomes waste or scrap. Furthermore, sheets, strips, and rod stock may be supplied either somewhat heavier or somewhat lighter than standard specifications. A variation of this kind must be recognized by the estimator and its possibility emphasizes the necessity of careful estimates.

SPECIFIC RAW MATERIALS WEIGHTS.—All weights of raw materials should be given in even figures or main fractions thereof, except for special high cost materials or for exceptionally small weights. The technique given throughout this Section is that developed by Olsen, to whom full credit is given for the methods. He has adopted a uniform percentage allowance of 5% for scrap. Because of this allowance it is unnecessary to specify weights in fine fractions or too far extended decimals. It should be remembered that in ordering materials for a production run, the unit figure is multiplied by the quantity figure when ordering raw materials. Every chance of mistake in performing this operation should be avoided. A plain, even figure for the unit weight will help in avoiding costly errors. Furthermore, a plain figure is easier and faster to use in computation.

The 5% weight allowance for scrap, which is Olsen's practice and which is used in this Section, is in some cases increased to 6% and sometimes decreased to 4¾% in order to yield an even total figure of weight.

Fig. 2 is an approximate table of even figures to be used in materials estimating. These figures are rounded out so that in some numbers they are neither at high nor low dividing points, but their use presents a practical method.

Below 5 lb., use decimals.

From		to		specify quantity in	
From	5	to	10 lb.,	specify quantity in	0.05 lb. steps
"	10	"	15 "	" " "	1/16 " "
"	15	"	30 "	" " "	1/8 " "
"	30	"	60 "	" " "	1/4 " "
"	60	"	90 "	" " "	1/2 " "
"	90	"	200 "	" " "	1 " "
"	200	"	500 "	" " "	2 " "
"	500	"	1,000 "	" " "	5 " "
"	1,000	"	2,000 "	" " "	10 " "
"	2,000	"	5,000 "	" " "	25 " "
"	5,000	"	10,000 "	" " "	50 " "
"	10,000 lb. up			" " "	100 " "

FIG. 2. Nearest Even Figure, in Pounds, for Raw Materials

It should be noted that in Fig. 2, with the exception of weights below 5 lb., fractions used are multiples. This tabulation is useful in specifying weights for all kinds of raw materials such as bars, rods, wire, sheet stock, and the like.

The weight is figured in the usual way in order to specify an even weight figure on drawing. Suppose a weight figured 25.130 lb.; Fig. 2 shows that from 15 to 30 lb. the weight should be given in ⅛-lb. steps. Therefore, the weight 25.130 lb. would be made 25⅛ lb., still leaving a scrap allowance above 4¾%. Assume that a weight figures 28.157 lb. This figure would have to be increased to 28¼ lb., which would still be below 6% for scrap. This weight could not be decreased to 28⅛ lb., since it would then allow less than 4¾% for scrap.

WEIGHT TABLES.—Olsen discovered in checking commercial tables of materials weights that they are developed from a variety of constants. These variations in many instances are sufficient to cause an excess of scrap. For this reason he developed a group of weight tables for common raw materials used in light machinery manufacture. These tables follow as Figs. 3 to 16.

The materials covered are metals, metal alloys and many nonmetallic materials, particularly such as are used in electrical manufacture. The form or shape of materials includes angles, I-beams, channels, T-beams, pipes, rods, sheets, strips, bars, tubings, wire, sand castings, and die castings. For each material there is given a formula for the weight of 1,000 pieces plus a 5% allowance for scrap. Included in this formula is a constant which is given in each tabulation. In addition there is indicated a preferred commercial size or gage for the material, and its exact weight in pounds per cubic inch.

Raw materials specified in Figs. 3 to 11 are of commercial grade, kind, and quality ordinarily used for manufacturing purposes. For these metals and metallic alloys the constants are the outgrowth of established practice, and have been used in figuring raw materials requirements for over a billion parts. For nonmetallic materials in Figs. 12 to 15, the weight constants are average figures and tend to run slightly heavy. Variations in materials of this kind must be expected in practice.

Formula for weight of 1,000 pieces plus 5% allowance for scrap: Weight (in lb.) = Sectional area times length times constant

Material	Preferred Commercial Size Specification or Standard Gage	Exact Weight in Lb. per Cubic Inch	Value of Constant in Weight Formula
Aluminum	Standard Codes	0.09650	101.3
Brass	"	.3075	322.9
Copper	"	.3215	337.6
Iron	"	.2778	291.7
Monel	"	.3230	339.2
Steel	"	.2833	297.5

FIG. 3. Weight Constants for Rolled and Drawn Shapes—Angles, I-Beams, Channels, T-Beams, and the Like

Formula for weight of 1,000 pieces plus 5% allowance for scrap: Weight (in lb.) = Thickness of wall times mean diameter times length times constant

Material	Preferred Commercial Size Specification or Standard Gage	Exact Weight in Lb. per Cubic Inch	Value of Constant in Weight Formula
Aluminum	Standard Wrought Iron Pipe Sizes	0 09682	319.4
Brass	"	.3069	1,012.0
Copper	"	.3227	1,064.0
Iron, Wrought	"	.2778	916.4
Lead	"	.4106	1,354.0
Nickel	"	.3190	1,052.0
Steel	"	.2833	934.6
Tin	"	.2650	874.2

FIG. 4. Weight Constants for Metal Pipes

Formula for weight of 1,000 pieces plus 5% allowance for scrap: Weight (in lb.) = Diameter times diameter times length times constant.

Material	Preferred Commercial Size Specification or Standard Gage	Exact Weight in Lb. per Cubic Inch	Value of Constant in Weight Formula
Aluminum	Diameter in fractions of an inch	0.09650	79.58
Brass (Screw Machine)	"	.3075	253.6
Bronze, Bearing	"	.3415	281.6
Bronze, Phosphor	"	.3195	263.5
Bronze, Tobin, Naval	"	.3036	250.4
Copper	"	.3215	265.1
Duralumin	"	.1010	83.3
Iron	"	.2778	229.1
Monel	"	.3230	266.4
Nickel, Pure	"	.3230	266.4
Nickel, Chromium	"	.3060	252.4
Nickel, Silver (Leaded)	"	.3996	329.6
Steel, Carbon	"	.2833	233.6
Steel, Drill Rod	"	.2850	235.0
Steel, High Speed	"	.3183	262.5
Steel, Nickel	"	.2833	233.6
Steel, Stainless (Chromium (12% CR)	"	.2810	231.7
Steel, Stainless (Chromium (20% CR)	"	.2777	229.0
Zinc	"	.2604	214.8

When using: Square rod, multiply weight by 1.273. Hexagon rod, multiply weight by 1.103. Octagon rod, multiply weight by 1.055.

FIG. 5. Weight Constants for Round Rods of Metals and Metallic Alloys

Formula for weight of 1,000 pieces plus 5% allowance for scrap: Weight (in lb.) = Thickness times width times length times constant.

Material	Preferred Commercial Size Specification of Standard Gage Gage or Thickness in fractions of an inch	Exact Weight in Lb. per Cubic Inch	Value of Constant in Weight Formula
Aluminum	American (B & S) Gage	0.09779	102.7
Brass, High Sheet	American (B & S) Gage	.3067	322.0
Bronze, Tobin, Naval	American (B & S) Gage	.3036	318.8
Copper	Rolled to Weight	.3215	337.6
Duralumin	American (B & S) Gage	.1008	105.8
Iron	U.S.S. Gage	.2778	291.7
Lead	Rolled to Weight	.4106	431.1
Monel	U.S.S. Gage	.3230	339.2
Nickel, Pure	U.S.S. Gage	.3195	335.5
Nickel Silver (18%)	American (B & S) Gage	.3180	333.9
Platinum, Pure	Decimals of an inch	.77448 (11.2945 Troy oz.)	813.20 (11,859.2 Troy oz.)
Steel, Cold Rolled	U.S.S. Gage	.2833	297.5
Steel, Stainless, Chromium 12%	U.S.S. Gage	.2810	295.1
Steel, Stainless, Chromium 20%	U.S.S. Gage	.2777	291.6
Steel, Terne Plate 8 Coat	U.S.S. Gage	0.2836	297.8
Steel, Tin Plate	Tin Plate Gage	.2833	297.5
Steel, Galvanized	Base in U.S.S. Gage	.2778 Plus 2.5 oz. per sq. ft.	
Tin (Block)	American (B & S) Gage	.2650	278.3
Zinc	Zinc Gage	.2604	273.4

Fig. 6. Weight Constants for Sheets of Metals and Metallic Alloys

Formula for weight of 1,000 pieces plus 5% allowance for scrap: Weight (in lb.) = Thickness times width times length times constant.

Material	Preferred Commercial Size Specification of Standard Gage Thickness in fractions of an inch, Width in fractions of an inch	Exact Weight in Lb. per Cubic Inch	Value of Constant in Weight Formula
Aluminum	American (B & S) Gage	0.09650	101.3
Brass, High Sheet	American (B & S) Gage	.3074	322.8
Bronze, Phosphor	American (B & S) Gage	.3160	331.8
Copper	American (B & S) Gage	.3215	337.6
Copper, Buss Bar		.3227	338.8
Nickel, Chromium Flats		.3060	321.3
Steel, Bar	U.S.S. Gage	.2833	297.5
Steel, Band and Hoop	Birmingham or Stubs Wire Gage	.2833	297.5
Steel, Cold Rolled	Birmingham or Stubs Wire Gage	.2833	297.5
Steel, Hot Rolled	Birmingham or Stubs Wire Gage	.2820	296.1
Steel, Shim	Birmingham or Stubs Wire Gage	.2833	297.5
Steel, Spring		.2833	297.5
Steel, Spring Clock	Decimals of an inch	.2800	294.0
Steel, Wire Ribbon	Birmingham or Stubs Wire Gage	.2833	297.5
Tin, Foil Sb 2 Pb 14		.3225	338.6

Fig. 7. Weight Constants for Strips and Bars of Metals and Metallic Alloys

Formula for weight of 1,000 pieces plus 5% allowance for scrap: Weight (in lb.) = Thickness of wall times mean diameter times length times constant

Material	Preferred Commercial Size Specification of Standard Gage Outside Diameter in fractions of an inch, Thickness of Wall	Exact Weight in Lb. per Cubic Inch	Value of Constant in Weight Formula
Aluminum, Seamless	Birmingham or Stubs Wire Gage	0.10145	334.7
Brass, Seamless	Up to and including 5/16 outside diam. in American (B & S) Gage. Above 5/16 outside diam. in Birmingham or Stubs Wire Gage	.3069	1,012.0
Brass, Brazed	American (B & S) Gage	.3113	1,027.0
Bronze, Commercial Brazed	American (B & S) Gage	.3154	1,040.0
Copper, Seamless	Birmingham or Stubs Wire Gage	.3227	1,065.0
Duralumin, Seamless	Fractions of an inch	.1010	333.2
Lead, Seamless	Fractions of an inch	.4106	1,354.0
Monel, Welded	Birmingham or Stubs Wire Gage	.3209	1,059.0
Nickel, Seamless (Pure)	Birmingham or Stubs Wire Gage	.3190	1,052.0
Nickel, Silver 18% Brazed	American (B & S) Gage	.3180	1,049.0
Steel, Seamless	Birmingham or Stubs Wire Gage	.2833	934.6
Zinc	American (B & S) Gage	.2604	859.0

FIG. 8. Weight Constants for Tubings of Metals and Metallic Alloys

Formula for weight of 1,000 pieces plus 5% allowance for scrap: Weight (in lb.) = Diameter times diameter times length times constant

Material	Preferred Commercial Size Specification of Standard Gage Diameter	Exact Weight in Lb. per Cubic Inch	Value of Constant in Weight Formula
Aluminum	American (B & S) Gage	0.09630	79.42
Brass	American (B & S) Gage	.3057	252.1
Bronze, Phosphor	American (B & S) Gage	.3210	264.7
Copper	American (B & S) Gage	.3212	264.9
Duralumin	American (B & S) Gage	.1010	83.30
Iron	Washburn & Moen Wire Gage	.2808	231.6
Lead	American (B & S) Gage or Birmingham or Stubs Wire Gage	.4106	338.6
Manganin	American (B & S) Gage	.3067	252.9
Monel	American (B & S) Gage	.3230	266.4
Nickel (Pure)	American (B & S) Gage	.3178	262.1
Nickel Silver 18%	American (B & S) Gage	.3180	262.3
Platinum (Pure)	Decimals of an inch or American (B & S) Gage	.77448 (11.2945 Troy oz.)	638.7 (9,314.2 Troy oz.
Solder, 50% Tin 50% Lead	American (B & S) Gage or English Standard Gage	.3380	278.8
Steel, Cold-Drawn	Washburn & Moen Wire Gage	.2833	233.6
Steel, Music	U.S.S. Music Wire Gage	.2833	233.6

FIG. 9. Weight Constants for Wire of Metals and Metallic Alloys

Formula for weight of 1,000 pieces plus 5% allowance for scrap: Weight (in lb.) = Volume times constant

Material	Exact Weight in Lb. per Cubic Inch	Value of Constant in Weight Formula
Aluminum	0.09548	100.2
Babbit (White Metal)	.3600	378.0
Brass, Yellow (70% Cu. 30% Zn)	.3050	320.2
Bronze, Bearing	.3415	358.6
Bronze, Gun	.3161	331.9
Copper	.3185	334.4
Duralumin	.1020	107.1
Gold 24K	.6956	730.4
Gold 18K Yellow	.5520	579.6
Iron	.2605	273.5
Lead	.4099	430.4
Mercury (Liquid)	.4904	514.9
Monel	.3200	336.0
Nickel	.3190	334.9
Silver, Pure	.3805	399.5
Silver, Sterling	.3714	390.0
Tin, White	.2634	276 6
Zinc	.2479	260.3

FIG. 10. Weight Constants for Sand Castings of Metals and Metallic Alloys

Formula for weight of 1,000 pieces plus 5% allowance for scrap: Weight (in lb.) = Volume times constant

Material	Exact Weight in Lb. per Cubic Inch	Value of Constant in Weight Formula
Aluminum (8 Cu)	0.114	120
(7 Cu 1.5 Si 2.5 Fe 1.5 Zn)	.106	111
(11.5 Si 2 Fe)	.0952	100
Lead Base (17 Sb)	.382	401
Tin Base (6 Cu 8 Sb)	.266	279
Zinc Base (8 Sn 4 Cu)	.253	266
(6 Sn 3 Cu)	.247	259
(2 Cu 4 Al)	.237	249

FIG. 11. Weight Constants for Die Castings of Metals and Metallic Alloys

Formula for weight of 1,000 pieces plus 5% allowance for scrap: Weight (in lb.) = Diameter times diameter times length times constant

Material	Preferred Commercial Size Specification of Standard Gage	Exact Weight in Lb. per Cubic Inch	Value of Constant in Weight Formula
Celluloid	Diameter in fractions of an inch	0.0558	46.0
Fiber, Phenol Formaldehyde (Bake.)	"	.0488	40.3
Fiber, Vulcanized	"	.0505	41.6
Glass Cane	Cane Glass Gage	.1024	84.5
Rubber, Hard Black	Diameter in fractions	.0426	35.1
Red	"	.0972	80.2
Brown	"	.0628	51.8

FIG. 12. Weight Constants for Round Rods of Nonmetallic Materials

Formula for weight of 1,000 pieces plus 5% allowance for scrap: Weight (in lb.) = Thickness times width times length times constant

Material	Preferred Commercial Size Specification of Standard Gage	Exact Weight in Lb. per Cubic Inch	Value of Constant in Weight Formula
Celluloid	Sheet Celluloid Gage	0 0503	52.8
Fiber, Horn	Decimals of an inch	.0400	42.0
Fiber, Phenol Formaldehyde (Bake)	Fractions of an inch	.0488	51.2
Fiber, Vulcanized	American (B & S) Gage or fractions of an inch	.0505	53.0
Glass, Common	Fractions of an inch	.0972	102.1
Leather	Fractions of an inch	.031	33.0
Mica, Commutator	Decimals of an inch	.0875	91.9
Mica, Flexible	Decimals of an inch	0700	73.5
Paper, Blot. Black	Decimals of an inch	.019	20.0
Paper, Blot. White	Decimals of an inch	.021	22.0
Paper, Fish	Decimals of an inch	.045	47.0
Paper, Manila	Decimals of an inch	.039	41.0
Paper, Red Rope	Decimals of an inch	.045	47.0
Rubber, Hard	American (B & S) Gage or fractions of an inch	.0426	44.7
Rubber, Soft Med	Fractions of an inch	.050	53.0
Rubber, Sponge	Fractions of an inch	.020	21.0
Vellumoid	Decimals of an inch	.037	39.0

FIG. 13. Weight Constants for Sheets of Nonmetallic Materials

Formula for weights of 1,000 pieces plus 5% allowance for scrap: Weight (in lb.) = Thickness of wall times mean diameter times length times constant

Material	Preferred Commercial Size Specification of Standard Gage	Exact Weight in Lb per Cubic Inch	Value of Constant in Weight Formula
Fiber, Phenol Formaldehyde (Bake.)	Inside Diameter and Thickness of Wall in fractions of an inch	0.0488	161
Fiber, Vulcanized	"	.0505	167
Glass	"	1024	338
Rubber, Hard, Black	"	.0426	140
Rubber, Soft, Red	"	0470	155

FIG. 14. Weight Constants for Tubings of Nonmetallic Materials

Formula for weights of 1,000 pieces plus 5% allowance for scrap: Weight (in lb.) Volume times constant

Material	Exact Weight in Lb. per Cubic Inch	Value of Constant in Weight Formula
Carbon	0.078	82.0
Casein Plastics	.049	51.5
Graphite	.091	96.0
Gypsum, Plaster of Paris	.045	47.0
Mica, Molding Sheet	.080	84.0
Paraffine	.032	34.0
Phenol Formaldehyde Powder (with canvas bracer)	.0495	51.9
Porceline	.087	91.0

FIG. 15. Weight Constants for Nonmetallic Molding Materials

Formula for weights of 1,000 pieces plus 5% allowance for scrap: Weight (in lb.) = Thickness times width times length times constant

Material	Exact Weight in Lb. per Cubic Inch	Value of Constant in Weight Formula
Bone	0.067	70.0
Cork, Natural	.0065	6.8
Cork, with Bituminous binder	.0093	9.8
Ivory	.068	71.5
Marble	0975	102.0
Quartz	.096	101.0
Soapstone	.098	103.0

FIG. 16. Weight Constants for Miscellaneous Nonmetallic Materials

ALLOWANCES FOR VARIOUS MATERIALS.—In the production of parts from rod or wire stock of smaller sizes, it is common practice to shear or clip off this material in such lengths as may be required for each part. In this method of handling there is no waste from cut-off tools such as results from larger sizes of stock. Total length of raw materials required for a given number of parts may be found by multiplying the exact length required to make one piece by number of pieces, adding a percentage to insure that the desired number of parts will be run. The shearing or clipping off operation is sometimes employed for larger sizes of rods, owing to the saving of stock which is effected by this method. Often such stock is cut hot, particularly where high-priced materials, such as magnet steel, are used. The saving of stock by this method often amounts to a considerable item.

Brass Rod

Diameter of Stock Inches	Width of Cut-off With Hole Inch	Width of Cut-off Solid Inch
Up to 1/8 incl.	1/32	1/32
9/64 to 5/16 incl.	1/16	1/16
21/64 to 1 incl.	5/64	3/32
1-1/64 to 3 incl.	1/8	3/16

Brass Pipe or Tubing

Diameter of Stock Inches	Width of Cut-off Inch
Wall up to 1/16 Thick. O.D. up to 1 incl.	1/32
Wall up to 1/16 Thick. O.D. 1-1/64 to 3 incl.	3/64
Wall 1/16 to 1/8 Thick. O.D. up to 1 incl.	1/16
Wall 1/16 to 1/8 Thick. O.D. 1-1/64 to 3 incl.	3/32

Steel Rod

Diameter of Stock Inches	Width of Cut-off With Hole Inch	Width of Cut-off Solid Inch
Up to 1/8 incl.	3/64	3/64
9/64 to 5/16 incl.	1/16	1/16
21/64 to 1 incl.	3/32	3/32
1-1/64 to 3 incl.	1/8	3/16

Steel Pipe or Tubing

Diameter of Stock Inches	Width of Cut-off Inch
Wall up to 1/16 Thick. O.D. up to 1 incl.	1/32
Wall up to 1/16 Thick. O.D. 1-1/64 to 3 incl.	3/64
Wall 1/16 to 1/8 Thick. O.D. up to 1 incl.	1/16
Wall 1/16 to 1/8 Thick. O.D. 1-1/64 to 3 incl.	3/32

FIG. 17. Widths of Cut-Off Tools

In operating screw machines for production of large quantities of interchangeable parts, cut-off tools are used which definitely do cut into scrap a certain proportion of each rod. Determination of the width of a cut-off tool is dependent upon many factors. Fig. 17 gives widths of cut-off tools for various kinds of materials and sizes of stock. These dimensions may be taken as representing good practice in reducing waste of stock to a minimum in the cutting-off operation.

In determining the length of rod stock for a given number of pieces, the width of the cut-off tool must be added to the length of the part in order to determine the length of stock required for one part. The total amount of raw materials required is this sum multiplied by number of pieces, plus 5% allowance for waste, and an allowance for pieces scrapped in the set-up of the machine and the length of stock required to grip and feed through the spindle. This last length varies from 3 to 6 in.

The percentage of stock used in cut-offs for short pieces, such as thin washers or nut blanks, goes as high as 20%. For a cap screw, ½ x 2 in. long, made from ¾-in. hexagonal stock, the loss is a good 50%. The average over-all allowance is about 12%, dependent upon the material hardness. Softer materials use thinner cut-off tools, hence there is less scrap.

Allowances for various materials are given in Fig. 18 as a percentage of the quantity determined from the manufacturing layout.

Kind of Allowance and Material	Per Cent	Kind of Allowance and Material	Per Cent
Over-all allowance:		Allowance for irregular shape and varying quality:	
Ordinary metal work	5	Hides (square foot basis)	25
Allowance for shrinkage and trimming:		Allowance for excessive breakage:	
Cotton duck	1	Glass rods	25
Rubber packing	1	Glass tubing	25
Allowance for weight variation:		Glass sheets	25
Aluminum sheets	2½	Allowance for defects:	
Steel bars	2½	Lumber No. 1 and No. 2 grades	35
Steel sheets	2½	Lumber, common	45
Brass wire	10		
Paper	10		
Pressboard	10		
Rubber	10		
Steel wire	10		

FIG. 18. Allowances in Cutting Various Materials

COST ACCOUNTING ALLOWANCE.—In addition to the materials estimating allowances given above, an over-all shrinkage allowance is sometimes added. It represents the difference between the manufacturing layout materials estimate plus compensating allowance, and the amount actually used, both estimate and actual consumption being computed for the plant as a whole for a year's operation. This allowance is often referred to as a cost accounting allowance. It may be as small as ½ of 1%, ranging upward to 4% or 5%.

Materials Estimating for Fabricated Products

ESTIMATING MATERIALS FOR HOOK BOLT.—The hook bolt (Fig. 19) is made from plain round stock and has unthreaded ends. For this reason it can be cut off with a clipping operation. Development

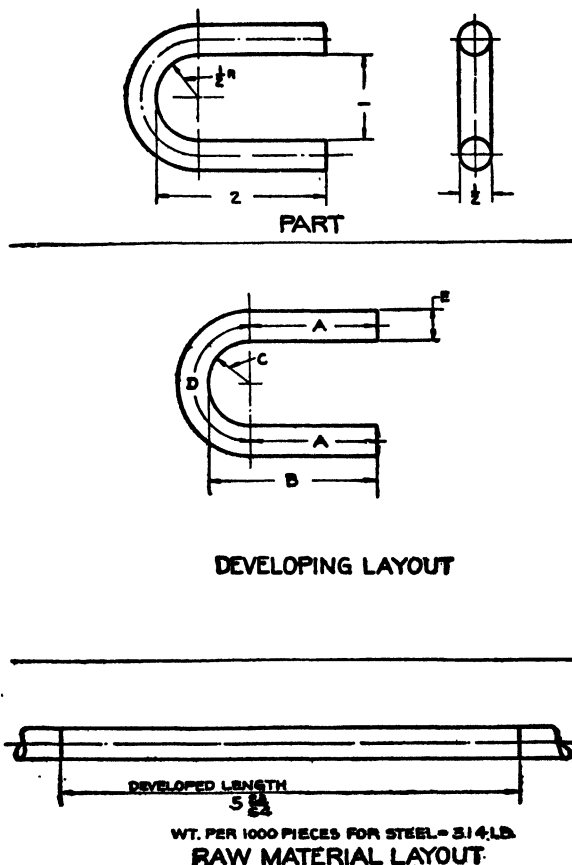



Fig. 19. Layout for Hook Bolt

layout is given in mid-part of drawing, and developed length and weight of material for 1,000 pieces is obtained as follows:

RAW MATERIAL LAYOUT

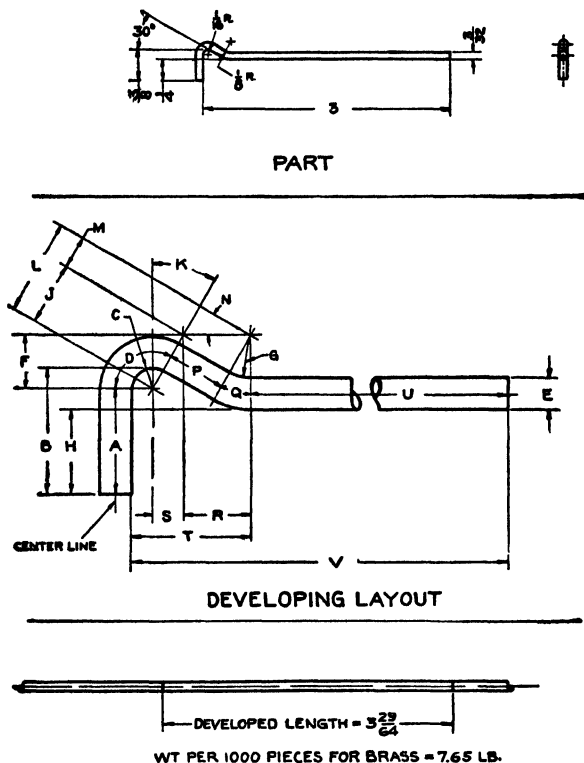



FIG. 21. Layout for a Brass Wire Hook

The diameter of wire used in making this part is 3/32 in. A plain clipping operation is sufficient to reduce the stock to proper blank length. The developed length and the weight of 1,000 pieces is worked out as follows:

$$A = B - C$$
$$D = (C + \tfrac{1}{2}E) \times \text{Constant for angle } D \ (120°)$$
$$F = G + E + H - A$$
$$J = \frac{F}{\text{Cosine } K \ (30°)}$$
$$L = G + E + C$$
$$M = L - J$$
$$P = M \times \text{Cotangent } N \ (30°)$$
$$Q = (G + \tfrac{1}{2}E) \times \text{Constant for angle } Q \ (30°)$$

$$R = \sqrt{P^2 + M^2}$$
$$S = \sqrt{J^2 - F^2}$$
$$T = R + S + C$$
$$U = V - T$$

Substituting numerical values,

$$A = .375 - .0625 = .3125$$
$$D = (.0625 + .0468) \times 2.0944 = .2289$$
$$F = .125 + .0937 + .250 - .3125 = .1562$$
$$J = .1562 \div .8660 = .1804$$
$$L = .125 + .0937 + .0625 = .2812$$
$$M = .2812 - .1804 = .1008$$
$$P = .1008 \times 1.7320 = .1746$$
$$Q = (.125 + .0468) \times .5236 = .0899$$
$$R = \sqrt{.1746^2 + .1008^2} = .2016$$
$$S = \sqrt{.1804^2 - .1562^2} = .0902$$
$$T = .2016 + .0902 + .0625 = .3543$$
$$U = 3.00 - .3543 = 2.6457$$

Developed length is:

$$A + D + P + Q + U = .3125 + .2289 + .1746 + .0899 + 2.6457$$
$$= 3.4516 \text{ or } 3\text{-}29/64$$

The raw materials weight for 1,000 pieces of this part made from brass is:

$$(.09375)^2 \times 3.453 \times (252.1, \text{ constant from Fig. 9}) = 7.650$$

Or 7.65 lb. per 1,000 pieces.

ESTIMATING MATERIALS FOR A BENT RECTANGULAR ROD.—Fig. 22 shows a rectangular bent rod with a cross section ¼ x 1 in. The method of developing the length of blank is as follows:

$$B = (K + \tfrac{1}{2}\,T) \times \text{Constant for angle } B\ (17°)$$
$$D = (L + \tfrac{1}{3}\,T) \times \text{Constant for angle } D\ (69° 30')$$
$$F = (M + \tfrac{1}{3}\,T) \times \text{Constant for angle } F\ (81°)$$
$$H = (N + \tfrac{1}{2}\,T) \times \text{Constant for angle } H\ (73° 30')$$

Substituting numerical values:

$$B = .750 \times .2967 = .2225$$
$$D = .458 \times 1.213 = .5556$$
$$F = .333 \times 1.4137 = .4708$$
$$H = .625 \times 1.2828 = .8018$$

The remainder of the lengths can be taken directly from the drawing, Fig. 22. The developed length is:

$$A + B + C + D + E + F + G + H + J = .375 + .2225 + .750$$
$$+ .5556 + .500 + .4708 + .375 + .8018 + .250 = 4.3007$$

The raw material length of one piece:

Developed length + Width of cut-off = 4.3007 + .200 = 4.5007.
Or 4½ in. long.

The raw material weight for 1,000 pieces of this part made from steel is:

$$\tfrac{1}{4} \times 1 \times 4.5 \times (296.1, \text{ constant from Fig. 7}) = 333.1 \text{ lb.}$$

Or 334 lb. per 1,000 pieces.

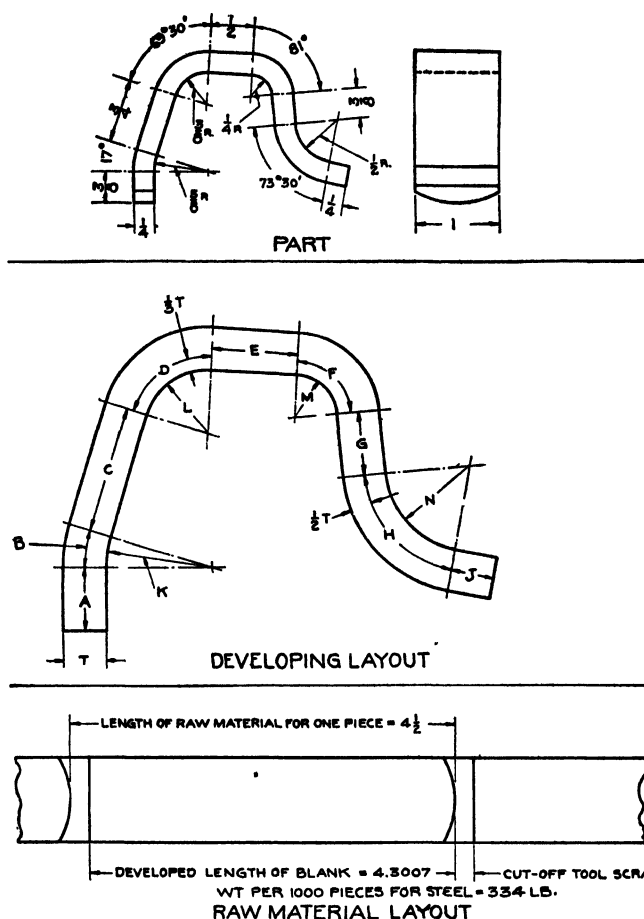



Fig. 22. Layout for Bent Rectangular Rod

By way of explanation, the two large radii K and N are figured by using one-half of the thickness of the stock plus the inside radius. The two smaller radii L and M are figured by using one-third of the stock plus the inside radius. The governing rule is: When the inside radius of the bend is twice or over twice the thickness of the stock, the developed length of the stock should be figured on a line one-half the distance from the inside edge of the stock. When the inside radius of the bend is less

than twice the thickness of the stock, the developed length of stock should be figured on a line one-third the distance from the inside edge of the stock. This rule applies to flat stock. For round stock the developed length is usually figured on the center line, that is, one-half the thickness of the stock is added to the length of the radius of bend in determining the developed length.

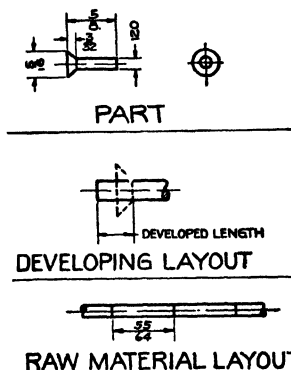



FIG. 23. Layout for a Flat Head Rivet

ESTIMATING MATERIALS FOR HEADED RIVET.—In estimating raw material lengths in the manufacture of headed parts, the length of blank is obtained by using the volume process. The volume of metal required to form the headed portion of the part is added to the volume of metal in the straight portion and the sum of the two will be the volume of metal in the blank. It may be readily seen, by referring to Fig. 23, that the head or swaged portion of the part is provided for in the length of wire. The total amount of material required for a given number of parts may be found by multiplying the lengths required for one part by the number of parts required, and adding 5% to the result to take care of waste material.

SCRAP ALLOWANCE FOR STAMPED PARTS.—Raw material for stamped parts is in sheet or strip form, the size of which is determined by the dimensions of the part to be stamped out. In practically all cases these dimensions must be sufficient to provide a narrow margin all around the piece that is to be made. This margin is called the scrap allowance and varies in width according to size of part, design of die, and thickness of material. Some parts of special design may be stamped without any allowance between part and edge. However, the general run must be punched from strips of sufficient width to provide a scrap edge. In blanked parts especially, this edge must be held to close limits. Due to these variations in practice, scrap allowance for stamped parts differs from that which is used for parts made from rod stock. On the latter the thickness of the cut-off tool and the regular percentage for waste determine the allowance; on the former, or stamped-out parts,

there is scrap between the parts and edges in addition to the regular percentage allowed for waste. McKnight emphasizes the importance of reducing these scrap allowances by showing a metal part on which the gross material scrap was originally 65% of the weight of raw materials and which was later reduced to 45% by improvement in methods of manufacture.

Thickness of Stock in Inches	Diameter of Blanks in Inches							
	1	2	3	4	5	6	7	8
	Scrap Allowance at Edge of Stock in Inches							
0.035	0.047	0.062	0.078	0.093	0.109	0.125	0.141	0.156
.050	.062	.078	.093	.109	.125	.141	156	.172
.065	.078	.093	.109	.125	.141	.156	.172	.187
.080	.093	.109	.125	.141	.156	172	.187	.187
.100	.109	.125	.141	.156	.172	.187	187	.187
.130	.141	.156	.172	.187	.187	.187	.187	.187
.160	.172	.187	.187	.187	.187	.187	.187	.187

FIG. 24. Scrap Allowance for One Thickness at Edge of Stock

Practical allowances for one thickness of stock at edge of stock are given in Fig. 24 for various thicknesses of stock and diameters of blank. These allowances are sufficient to permit high-speed production which, under many conditions, is more economical than adherence to extremely close raw materials estimating.

When thickness of stock or diameter of blank is of a dimension lying between the figures given in Fig. 24, the figure next largest in size should be used. For stock 3/16 in. or over in thickness, the scrap allowance between the part and edges should be made equal to stock thickness. It should be noted in the above figure, that the ratio of scrap allowance size increases in proportion to diameter of blank.

In some cases theoretical scrap allowance between parts may be as low as 7/10 of stock thickness, and when cases of this kind arise it is good practice to consider carefully the size of the blank, the kind of material, and the thickness of stock before using extremely small figure in estimating, A good, safe, general rule to use, and one which is in harmony with the previously mentioned scrap allowance, is: Scrap width between blanks should be the same as stock thickness for all stocks above 1/32 in. in thickness. For stocks 1/32 in. or less in thickness, use 1/32-in. allowance between blanks.

The percentage allowance for waste as applied to stamped or blanked out parts is in most cases made the same as for other stock, 5% additional raw material being provided to take care of waste.

SCRAP AND WASTE FROM STAMPED PARTS.—There are three main items to be considered in reducing or minimizing materials losses from stamped parts: waste, scrap, and spoilage. Waste is that part of the strip or sheet which is left after parts have been blanked out. This item must be accepted as a necessary item of the cost of parts. It can be held to a minimum by the use of modern methods in designing punch-press tools, and by careful material layouts and estimating of raw materials quantities. Scrap consists of unusable raw materials or stock due to incorrect dimensions, improper material layouts, or selection of mate-

rial which leaves excessive leftover ends of the strips. This loss may sometimes be caused by a too liberal allowance in material layout. Spoiled parts include those made to wrong dimensions, those damaged in handling, and those imperfect due to carelessness in manufacturing. The material in such parts has little value as only a small proportion may be reworked and reused. Most of it must be sold as junk metal.

It is impossible to establish definite rules to follow for reduction of these classes of waste in stamped parts. However, a guide in analyzing for such reduction includes these items: selection of raw materials which can be used for more than one blank; selection of blanking operation which will yield more than one blank; standardization on kinds of raw materials; standardization of thickness of materials; standardization of widths of strip.

INFLUENCE OF GRAIN DIRECTION ON MATERIAL LAYOUTS.—Surfaces of sheet or strip stock when magnified show stripes and ridges running lengthwise of the material (see Fig. 25). This condition is a physical property of all rolled and drawn metals and is commonly known as "grain direction." Metals will form or bend across the grain better than with the grain, therefore this characteristic should be considered in the layout of parts where strength and flexibility are required. Special attention must be given to parts having a sharp right angle bend; in such a case the bend must be across or approximately across the grain of the material to secure parts that will not crack or break when bending or forming. This requirement necessitates a proper arrangement of blanks in material layout, which in turn has an influence upon the estimating of raw materials requirements. In practice, for small bends 45° or less, direction of grain may be ignored owing to the slight danger of cracking and breaking. For parts bent 90° or greater, grain direction need not necessarily be exactly across grain but may be in any position from that to a direction of 45° with direction of grain.

ESTIMATING MATERIALS FOR COMMON WASHER.—The first step in material layout for a common washer is consideration of the quantity to be produced. If, for instance, 10,000 pieces are to be made, layout in most cases would be in single strips as shown in Fig. 26. This method presupposes blanking one piece at each stroke of the press Allowance for stock between parts and edges of raw stock is taken as 70% of stock thickness. This small allowance is made possible by the narrow width of stock. Take, for example, the part shown in the drawing of Fig. 26. Thickness of stock is given as .0625 in. Using a 70% allowance constant, the theoretical scrap allowance is: $.0625 \times .7 = .04375$. For convenience in figuring large quantities, this decimal fraction is increased to the nearest largest common fraction, which is 3/64 in.

The multiple is found by taking the diameter of one part and adding the scrap allowance to it. In this case it would be 1 in. + 3/64 in. or 1-3/64 in. as shown in the illustration. The same scrap allowance would also be used in determining width of stock. Taking part diameter B and adding the stock allowance to each side, the width of strip must be 1-3/32 in. Weight of raw material for 1,000 pieces of this particular part made from steel stock is determined by the regular formula, which includes 5% for scrap. 1-3/32 × 1/16 × 1-3/64 × (296.1, constant from Fig. 7) = 21.18, or 21¼ lb. per 1,000 pieces.

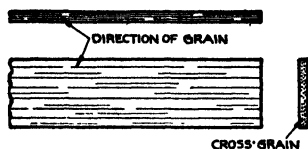



Fig. 25. Grain of Sheet Metal Stock

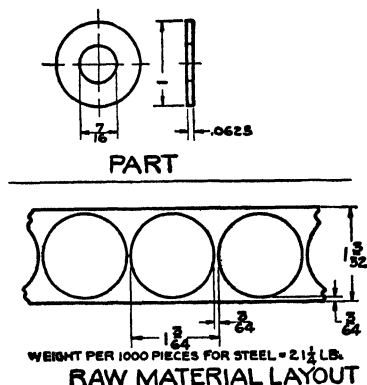



Fig. 26. Layout for Common Washer

ESTIMATING MATERIALS FOR A RHOMBOID BLANK.—In material layout for parts of the type where the blank has parallel sides, the straight sides of the part necessitate a spacing of raw materials to leave a narrow margin of stock at both ends of the part which are parallel to the edges of the raw stock (see Fig. 27). In this case it is

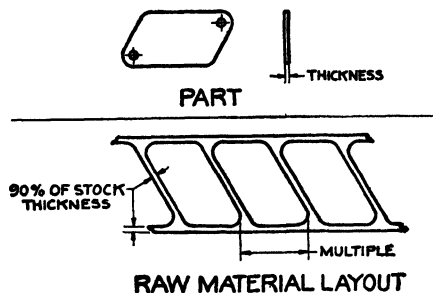



Fig. 27. Layout for Rhomboid Blank

always advisable to allow at least .9 of stock thickness, or as previously stated, 90% of thickness for both scrap between parts and for scrap between end of part and edge of raw material. In case this theoretical figure is found to be some uneven decimal, it should be increased to the next largest fractional size.

ESTIMATING MATERIALS FOR INSULATION PANEL.—In Fig. 28 is shown the material layout for panels to be made from commercial size sheets of insulation material. Here the process of producing parts is by means of a sawing operation instead of shearing as is common in working metals. Insulated materials may be sawed, sheared,

punched, and machined, in much the same manner as metal. However, care must be exercised in selecting methods, depending upon thickness of stock, size of blank, particular kind of material, equipment to be used, and number of parts to be produced.

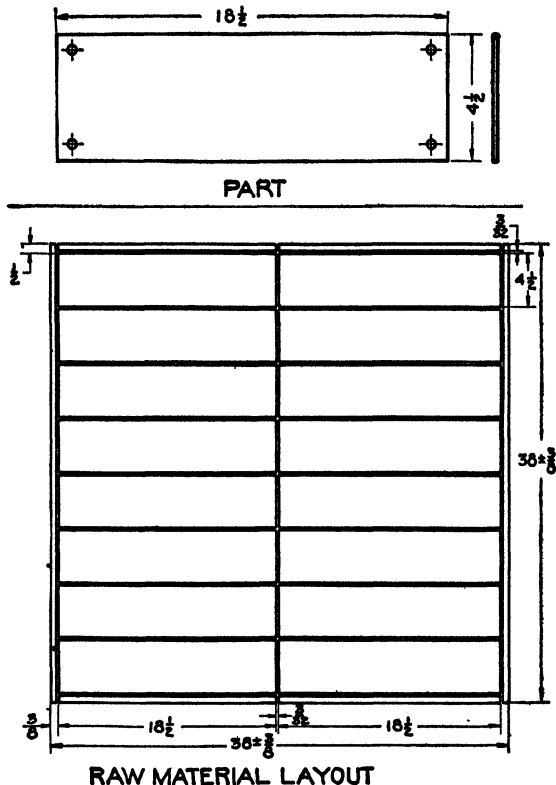



Fig. 28. Layout for Insulation Panels

In the layout as shown, a 38 x 38-in. commercial sheet is found to be correct for 16 blanks; in dividing this sheet an allowance is made from the starting side to insure a clear edge on the blank. Allowance is shown on top and left sides of sheet and figured in such a manner that there will always be a scrap strip left from the minimum size of sheet, in both length and width. Weight of raw material per 1,000 pieces should be estimated from 16 blanks per sheet. Take 16 blanks as the weight of one sheet and to the total add 5% for scrap, following the general rule for other materials.

Material layouts of this kind, whenever possible, should make use of sheets of commercial sizes as these are generally cheaper and more easily obtained than sheets cut to specifications. In some cases it will be found advisable to purchase strips cut to accurate dimensions which would give the required blank merely by using a simple cut-off operation. In other cases, owing to the type of equipment at hand, blanks can be purchased cut to size cheaper than they can be made from raw material. The determining factor in selection of raw material is equipment on hand for reducing it to blank sizes.

ESTIMATING MATERIALS FOR INSULATION SHEET.—Fig. 29 shows a sheet of insulated material similar to the one in the preceding estimate. The problem of materials layout here, however, is to divide the sheets into strips of suitable size for use in a punch press. The part is a circular disc and the preferable arrangement is to punch

RAW MATERIAL LAYOUT

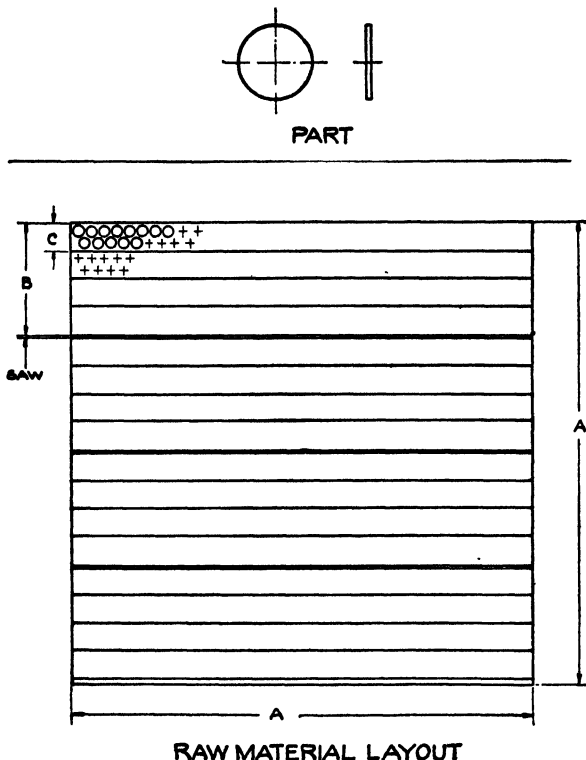



Fig. 29. Layout for Insulation Disc

in a double row as shown in the illustration. The process of reducing raw material to strips of proper width is first to divide the sheet into four equal parts by sawing and then to split each of these into four other parts by shearing. The resulting strips will be of the correct width to punch out a double row of discs.

The first large division of the sheet is done to obtain strips of suitable widths for shearing. The number of large strips to be sawed out must be so proportioned as to be within the minimum size of sheet and must also allow for waste of saw slots. The determining factor in arrangement of strips to be taken from the sheet is the quantity of parts to be made; for example, providing the above part were to be made in a small quantity, the part would be laid out in a single row which would necessitate a different arrangement of strips.

In material layouts for insulating materials, the factor of waste between parts, and between parts and edge, must be larger than is customary for metal. In most cases, 1½ times stock thickness will prove to be a satisfactory average. The weight of raw material per 1,000 pieces may be determined by finding the number of pieces per sheet and adding the regular 5% allowance for scrap.

ESTIMATING MATERIALS FOR PLAIN SHELL WITH DOUBLE SEAM.—A plain rolled-up shell joined with a common double seam is shown in Fig. 30. The ends of the blank are so formed that one hooks into the other. To estimate raw materials for a shell of this type, it is necessary to include stock for seams in the blank size. Material ordinarily used for parts of this kind is tin plate or other commercial sheets having a coating of tin. The reason for the use of tin is to produce seams that are readily soldered. To insure free running of solder and consequently satisfactory seams, it is the general practice to figure joint slightly loose. For this reason it is good practice to estimate stock requirements somewhat in excess of what would be considered good practice for parts which are not to be soldered.

The method of material layout and blank development differs from that of previous example in that length of raw material for the seam is determined in this case by a large-sized layout. The layout method may be considered as being sufficiently accurate for work of this particular class, and in connection with this statement it may be well to note that in many complicated problems it is always good practice to make use of large scale layouts "and step the length off." The double seam length may, of course, be determined by figures. However, it is safer always to use both methods when large production is involved.

Material layout in this case differs from regular strip layouts in that the blanks are obtained from commercial sheet sizes. From the illustration it may be readily seen that 32-shell blanks are sheared from one sheet with a waste strip on two sides, and, as this type of blank is cut on a straight shearing machine, the waste strip must be approximately ¾ in. to allow operators to handle material readily. Scrap allowance in this type of problem should be figured as follows: Using the illustration as an example, the weight of the complete sheet should be figured for 32 pieces and an additional 5% allowance should be added to total weight per 1,000.

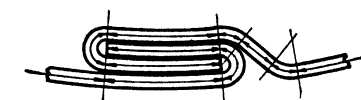
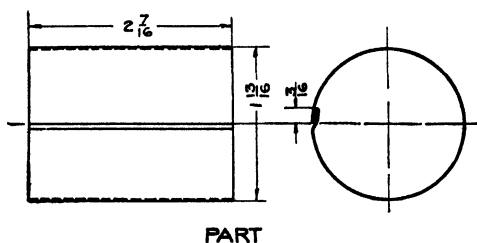
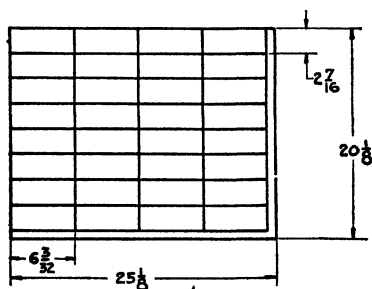



FIG. 30. Layout for Double Seamed Shell

ESTIMATING MATERIALS FOR A ¼-TURN TWIST.—Estimating materials for a twisted part is difficult, as a number of factors influence the length of a strip of raw material which will give the required length for twisting. Relationship of width and thickness of material is one of these factors. However, it is possible to determine approximately the amount of variation. A fairly accurate formula which has proved its worth is this: The developed blank for a twisted part is 1/32

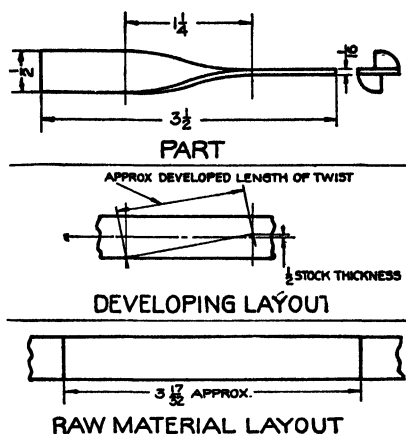



Fig. 31. Layout for ¼ Turn Twist

longer than the finished part; that is, the part is shortened by the twisting action (see Fig. 31). In view of the fact that kind of material and width and thickness play such important parts in determining the shortening effect of the twist, it is advisable to make a sample for checking the developed length of such parts before the material is finally specified, especially where large quantities are concerned.

MATERIAL REQUIREMENTS FOR DRAWN BLANKS.—In determining raw material requirements for drawn parts, a major consideration in most cases is area of metal necessary to form the part. The general rule is: Drawn part blanks are figured by area. In theory the projected area of a drawn part is the same as area of the blank from which it was made. In practice there is generally a slight difference in these areas due to stretching of the metal. The most accurate method in determining the correct blank size is by "cut-and-try," or by checking the size by an actual drawing operation in the press. However, this method is unsatisfactory from production and cost standpoints, so it is common practice to determine the approximate amount of material per blank from its size and shape, in order that raw material may be specified and purchased before tools are finished.

The method used is this: The most common forms of drawn parts have a radial shape in the bottom and corners. Fig. 32 gives a ratio of thickness of stock to inside radius and the corresponding constant for proportions of blanks sufficient to cover all ordinary practice. The ratio is found by dividing thickness of stock by inside radius of part. When the corresponding constant is selected, the length of arc for a 90° corner is found by multiplying the inside radius of part by this constant. The length of this arc is called the neutral arc and is the determining factor for area of material in curved or radial corners of a drawn part. It should be noted that this procedure is correct only for 90° corners.

Ratio	Constant	Ratio	Constant	Ratio	Constant	Ratio	Constant	Ratio	Constant	Ratio	Constant
Use 1/2 Thick		1.110	2.221	1.710	2.473	2.310	2.849	3.510	3.523	5.890	4.636
0.760	2.160	1.120	2.224	1.720	2.479	2.320	2.855	3.550	3.541	5.930	4.655
.770	2.161	1.130	2.227	1.730	2.486	2.330	2.861	3.590	3.560	5.970	4.673
.770	2.161	1.140	2.230	1.740	2.492	2.340	2.868	3.630	3.579	6.010	4.692
.775	2.162	1.150	2.234	1.750	2.498	2.350	2.874	3.670	3.587	6.050	4.710
.780	2.162	1.160	2.237	1.760	2.504	2.360	2.880	3.710	3.616	6.090	4.729
.785	2.163	1.170	2.240	1.770	2.511	2.370	2.886	3.750	3.634	6.130	4.748
.790	2.163	1.180	2.243	1.780	2.517	2.380	2.893	3.790	3.653	6.170	4.766
.795	2.164	1.190	2.247	1.790	2.523	2.390	2.899	3.810	3.671	6.210	4.785
.800	2.164	1.200	2.250	1.800	2.529	2.400	2.905	3.850	3.690	6.250	4.803
.805	2.165	1.210	2.253	1.810	2.536	2.410	2.911	3.890	3.708	6.290	4.822
.810	2.166	1.220	2.256	1.820	2.542	2.420	2.918	3.930	3.727	6.330	4.840
.815	2.166	1.230	2.260	1.830	2.548	2.430	2.924	3.970	3.746	6.370	4.859
.820	2.167	1.240	2.263	1.840	2.554	2.440	2.930	4.010	3.764	6.410	4.877
.825	2.167	1.250	2.266	1.850	2.561	2.450	2.937	4.050	3.783	6.450	4.896
.830	2.168	1.260	2.269	1.860	2.567	2.460	2.943	4.090	3.801	6.490	4.915
.835	2.168	1.270	2.273	1.870	2.573	2.470	2.949	4.130	3.820	6.530	4.933
.840	2.169	1.280	2.276	1.880	2.580	2.480	2.955	4.170	3.839	6.570	4.952
.845	2.170	1.290	2.279	1.890	2.586	2.490	2.962	4.210	3.856	6.610	4.970
.850	2.170	1.300	2.282	1.900	2.592	2.500	2.968	4.250	3.875	6.650	4.989
.855	2.171	1.310	2.286	1.910	2.598	2.510	2.974	4.290	3.893	6.690	5.008
.860	2.171	1.320	2.289	1.920	2.605	2.520	2.980	4.330	3.912	6.730	5.026
.865	2.172	1.330	2.292	1.930	2.611	2.530	2.987	4.370	3.930	6.770	5.045
.870	2.172	1.340	2.295	1.940	2.617	2.540	2.993	4.410	3.949	6.810	5.063
.875	2.173	1.350	2.299	1.950	2.623	2.550	2.999	4.450	3.968	6.850	5.082
.880	2.173	1.360	2.302	1.960	2.630	2.560	3.005	4.490	3.986	6.890	5.100
.885	2.174	1.370	2.305	1.970	2.636	3.570	3.012	4.530	4.005	6.930	5.119
.890	2.175	1.380	2.309	1.980	2.642	2.580	3.018	4.570	4.023	6.970	5.138
.895	2.175	1.390	2.312	1.990	2.648	2.590	3.024	4.610	4.042	7.010	5.156
.900	2.176	1.400	2.315	2.000	2.655	2.600	3.031	4.650	4.060	7.050	5.175
.905	2.176	1.410	2.318	2.010	2.661	2.610	3.037	4.690	4.079	7.090	5.193
.910	2.177	1.420	2.322	2.020	2.667	2.620	3.043	4.730	4.098	7.130	5.212
.915	2.177	1.430	2.325	2.030	2.673	2.630	3.049	4.770	4.116	7.170	5.230
.920	2.178	1.440	2.328	2.040	2.680	2.640	3.055	4.810	4.135	7.210	5.249
.925	2.178	1.450	2.331	2.050	2.686	2.650	3.062	4.850	4.153	7.250	5.268
.930	2.179	1.460	2.335	2.060	2.692	2.660	3.068	4.890	4.172	7.290	5.286
.935	2.180	1.470	2.338	2.070	2.698	2.670	3.074	4.930	4.190	7.330	5.305
.940	2.180	1.480	2.341	2.080	2.705	2.680	3.081	4.970	4.209	7.370	5.223
.945	2.181	1.490	2.344	2.090	2.711	2.690	3.087	5.010	4.228	7.410	5.342
.950	2.181	1.500	2.348	2.100	2.717	2.700	3.093	5.050	4.246	7.450	5.360
.955	2.182	1.510	2.351	2.110	2.724	2.710	3.099	5.090	4.265	7.490	5.379
.960	2.182	1.520	2.354	2.120	2.730	2.750	3.118	5.130	4.283	7.530	5.398
.965	2.183	1.530	2.360	2.130	2.736	2.790	3.143	5.170	4.302	7.570	5.416
.970	2.183	1.540	2.367	2.140	2.742	2.830	3.168	5.210	4.320	7.610	5.435
.975	2.184	1.550	2.373	2.150	2.749	2.870	3.193	5.250	4.339	7.650	5.453
.980	2.185	1.560	2.379	2.160	2.755	2.910	3.218	5.290	4.358	7.690	5.472
.985	2.185	1.570	2.385	2.170	2.761	2.950	3.243	5.330	4.376	7.730	5.490
.990	2.186	1.580	2.392	2.180	2.767	2.990	3.269	5.370	4.395	7.770	5.509
.995	2.186	1.590	2.398	2.190	2.774	3.030	3.293	5.410	4.413	7.810	5.528
1.000	2.187	1.600	2.404	2.200	2.780	3.070	3.319	5.450	4.432	7.850	5.546
1.010	2.188	1.610	2.410	2.210	2.786	3.110	3.337	5.490	4.450	7.890	5.565
1.020	2.191	1.620	2.417	2.220	2.792	3.150	3.356	5.530	4.469	7.930	5.583
1.030	2.195	1.630	2.423	2.230	2.799	3.190	3.374	5.570	4.488	7.970	5.602
1.040	2.198	1.640	2.429	2.240	2.805	3.230	3.393	5.610	4.506	8.010	5.620
1.050	2.201	1.650	2.435	2.250	2.811	3.270	3.411	5.650	4.523	8.050	5.639
1.060	2.204	1.660	2.442	2.260	2.818	3.310	3.430	5.690	4.543	8.090	5.658
1.070	2.208	1.670	2.448	2.270	2.824	3.350	3.449	5.730	4.562	Use 1/3 Thick	
1.080	2.211	1.680	2.454	2.280	2.830	3.390	3.467	5.770	4.580		
1.090	2.214	1.690	2.460	2.290	2.836	3.430	3.486	5.810	4.599		
1.100	2.217	1.700	2.467	2.300	2.843	3.470	3.504	5.850	4.618		

FIG. 32. Ratios and Constants for Drawn Blanks

Calculation of length of neutral arc for a 90° form is simple. Assume a stock thickness of 1/16 in. and an inside corner radius of 5/64 in. Ratio of thickness of stock divided by inside radius is: 1/16 ÷ 5/64, or .0625 ÷ .0781 = .800, which is the ratio. Turning to Fig. 32, opposite ratio .800 is found the constant 2.164. The inside radius multiplied by this constant will give the length of the required arc, or .0781 × 2.164 = .169 in., length of the arc.

Turning to Fig. 32, no constants are given for ratios below .760 or for ratios above 8.090. If the ratio of a given part is below the smallest in the figure, one-half of the thickness in metal is added to the inside radius; if the ratio is above the largest one given in the figure, one-third of the stock thickness is added to the inside radius to find the neutral radius.

METHOD OF ESTIMATING MATERIALS FOR PLAIN DRAWN CUP.—Fig. 33 shows a common drawn cup. Two centers of gravity are indicated in separate parts of the piece, thus indicating areas

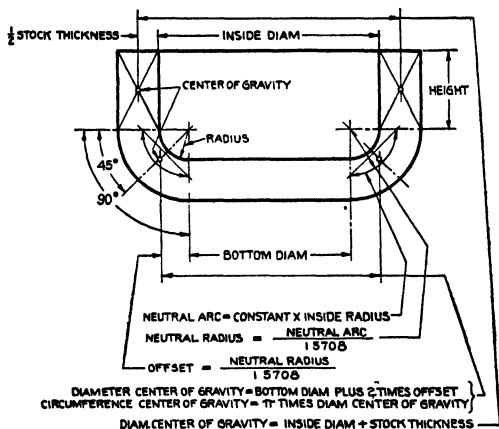



FIG. 33. Layout for Plain Drawn Cup

to be used in figuring the developed length of a blank. The circumference of the cylindrical part is found by multiplying the diameter at the center of gravity by 3.1416. Multiplying this product by the height of the cylinder gives the area of the cylindrical portion of the part. The area of the bottom portion is found as the area of a circle, using the formula 3.1416 r^2; the corresponding diameter is taken inside the corner radii. Stock for the radial corner in the bottom of the part is slightly more complicated to estimate. It is necessary to determine the neutral radius, center of gravity, length of arc, and offset. When these factors are determined, the length of the neutral arc is multiplied by the diameter at the center of gravity, and this result is multiplied by 3.1416 to give total area of stock required for this portion of the part. The final

area is found by adding the results of all the calculations for various portions and dividing the total sum by .7854 and extracting the square root of the result.

By way of further explanation, the center of gravity in a cylindrical part is figured in the center of the pieces, that is, the inside area plus one thickness of stock. The neutral radius for any of the ratios listed in Fig. 32 is found by dividing the arc by 1.5708. This holds for 90° angles only. Constants in the figure times the inside radius give the length of the neutral arc of a 90° angle. The offset equals the distance from the outside diameter of the bottom portion to the point of center of gravity. Offset is found by dividing the neutral radius by 1.5708, for 90° angles only. The center of gravity for the radial portion is found by adding twice the offset to the bottom of the diameter.

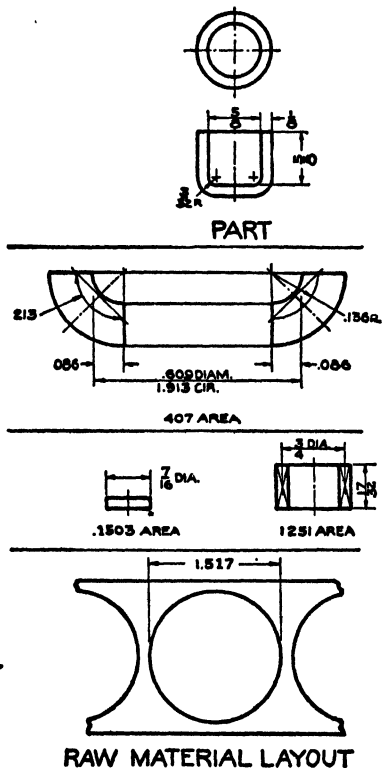



Fig. 34. Layout for Plain Drawn Shell

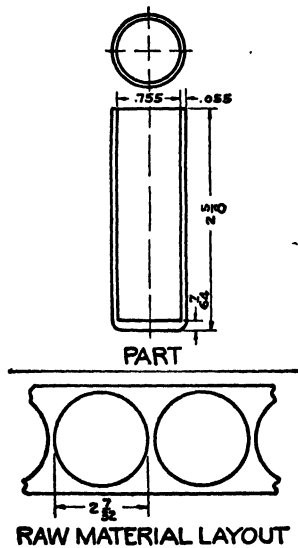



Fig. 35. Layout for Shell with Varying Thicknesses of Wall

ESTIMATING MATERIALS FOR PLAIN DRAWN SHELL.—Calculations for estimating the material for a plain drawn shell (Fig. 34), using the method explained above, are:

Radial portion. Stock thickness .125, divided by the inside radius .093 = 1.344, or the ratio.

Turning to Fig. 32, opposite 1.340 is 2.295, the constant for the ratio.
Inside radius .093, times the constant 2.295 = .213, or the neutral arc.
Neutral arc divided by 1.5708 (the constant for 90°) = .136 or the neutral radius.
Neutral radius .136, divided by the constant for 90° (1.5708) = .086, or the offset.
Two times the offset .086, plus the bottom diameter .437 = .609, or the diameter at center of gravity.
Diameter at center of gravity .609, times 3.1416 = 1.913, or the circumference at center of gravity.
Circumference at center of gravity 1.913, times neutral arc .213 = .407, or the area of the radial portion.

Cylindrical portion. Inside diameter .625, plus one stock thickness .125 = .750, or the diameter at center of gravity.

Diameter at center of gravity .750, times 3.1416 = 2.356, or the circumference at center of gravity.
Circumference at center of gravity 2.356, times height .531 = 1.251, or the area of the cylindrical portion.

Circular bottom portion. Area of bottom = area of a .4375 diameter circle, or .1503.

Total area of the blank is made up of:

.1503 area of bottom
1.2510 area of cylindrical portion
.4070 area of radial portion
1.8083 total area

Total area. 1.8083 ÷ .7854 = 2.302. Taking the square root of this result, the diameter of the blank is found to be 1.517 in.

ESTIMATING MATERIALS FOR DRAWN SHELLS OF VARIOUS THICKNESSES.—Fig. 35 shows a drawn shell in which there is a decrease in stock thickness from 7/64 in. in the bottom to .055 in. in the side walls. Common practice in estimating raw materials requirements for a blank to produce a part of this kind is to figure the blank size from the volume of metal in the part. The method of figuring is:

Cylindrical portion.

$$\left(\frac{\pi \times .865^2}{4} - \frac{\pi \times .755^2}{4}\right) \times (2.625 - .109)$$

$$= \frac{\pi \times .178 \times 2.516}{4} = .3517 \text{ cu. in.}$$

Circular bottom portion.

$$\frac{\pi}{4} \times (.865 - 2 \times .109)^2 \times .109 = .0358 \text{ cu. in.}$$

Quarter circle ring portion. For this kind of work, the following formula can be set up according to Guldinus rule:

Let D be the outside diameter of the ring.
Let r be the radius of the segment.
Thus, r will at the same time signify the height of the ring.

$$\frac{\pi \times r^2}{4} \times \pi \times \left[D-2r + 2 \times \frac{.6002}{\sqrt{2}} \times r\right] = \text{Volnme}$$

This expression can be simplified to:

$$2.467\ r^2\ (D - 1.151\ r) = \text{Volume}$$

Using this formula,

$$2.467 \times .109^2 \times (.865 - 1.151 \times .109) = .0217 \text{ cu. in.}$$

Adding the three parts together:

.3517 cu. in., volume in the cylindrical portion
.0358 cu. in., volume in the circular bottom portion
.0217 cu. in., volume in the quarter circle ring portion
.4092 = Total number of cu. in. in the part

Theoretical blank size is:

$$\frac{\pi \times D^2}{4} \times .109 = .4092 \text{ cu. in.}$$

$$D = 2.186 \text{ in.}$$

Theoretically the diameter of the blank will be approximately 2-3/16 in. but on the material layout the size in increased to 2-7/32 in., allowance being made for trimming of the shell edge. In adding allowances it should be noted that it is always better to figure blank sizes on the large side.

ESTIMATING MATERIALS FOR DRAWN TAPERED CYLINDER.—The method used to obtain the area of a tapered cylinder is to multiply the circumference of the center of gravity by the height

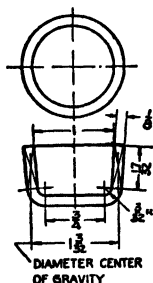



FIG. 36. Layout for Drawn Tapered Cylinder

of one side, this height being taken parallel to the side. In the illustration (Fig. 36) this height is 17/32 in. In straight cylinders, the center of gravity comes in the middle between the inside and outside diameters. In tapered cylinders this center of gravity comes midway between the

smallest inside diameter and the largest outside diameter. In Fig. 36 the diameter of the center of gravity is 1-3/32 in., which is the dimension between 1¼ in. and 15/16 in., outside and inside diameters, respectively.

Estimating Foundry and Plating Materials

FOUNDRY MATERIALS.—In estimating materials for the foundry, the prime requisite is the weight of materials needed. This weight can be ascertained by computing the volume in cubic inches of a completed casting and multiplying the volume by the weight in pounds per cubic inch of the material used. (See Fig. 10.) The volume of the core must be subtracted from the volume of the piece. whenever cores are used. There are various losses of material in the foundry which make estimating more difficult than mere formula work. These losses group under three headings: melting, casting, and cleaning. **Melting losses** are due to oxidation, combination of chemical elements in the material with the slag, loss when cleaning out the cupola or furnace, especially when dropping the bottom of the cupola at the end of the run, shrinkage of the metal itself, slopping while pouring from furnace to ladle. **Casting losses** are loss of weight due to ignition of gases within the flask, loss when pouring from bull ladle to hand ladle, loss when pouring from ladle into flask. **Cleaning losses** are in chipping or grinding parting lines, in tumbling off the fins, in chemical reaction in pickling barrels, and in sand blasting. **Total losses** range in amount from 5% through 12%. Risers and gates, which are cut off, are not counted as a loss. They are recoverable and are usually remelted in the next heat. In estimating the material needed for melting, however, risers and gates are covered by a percentage allowance.

Foundry losses are dependent upon many variables. These are kind of metal used, ferrous or nonferrous, and chemical content of each metal, as yellow or red brass; type of cupola used and/or type of fuel—wood, coke, coal, oil—used in charging other types of furnaces, electric or gas-fired; types of ladles, number of transfers from ladle to ladle until final pouring into mold; type of flask used, whether hand or machine molding methods are used. Ordinarily the smaller the size of flask used the larger the percentage of pouring loss. The skill and care taken in tamping and rapping the flask determines the loss which may arise later in the machining of the castings. If flasks are tamped correctly, the proper amount of metal will be on the castings for machining. If flasks are not correctly tamped, there may be too little or too much metal on the casting. Accurate calculation of these variables depends upon intimate knowledge of the conditions in the foundry, in which case some of the variables may become constants.

LOSSES IN MACHINING CASTINGS.—Some of the machine-shop operations have already been considered. From the foundry is obtained the amount of material needed for the casting. To this is added the weight of the metal to be used in machining and the various losses. Losses are divided into three classes: scrap, waste, and spoilage. Of these the scrap and waste are variables and are somewhat indeterminable; spoilage can be predicted from past performances. When both

rough and finished dimensions are known, for example, ⅛ in. planing cut to be taken from a 3 x 4 in. surface, the amount of material scrap can readily be determined. Whether all of this scrap is recoverable is unimportant from the estimating point of view. The usual formulas for volume determine the amount of material needed in the machined item, and the amount to add for scrap or chips, etc., can be closely calculated. A cut-off operation takes into account the width of the cut-off tool. (See Fig. 17.) Variables entering into these calculations are thickness of casting, due to mold being tamped too loosely or rapped too hard, hard spots, blow holes, slight core shifts, etc., scrap due to chucking or centering up, short ends of rods and bar stock, etc. The usual custom is to calculate the known amount of metal needed, add the amount for machining and then add a percentage for the known losses due to conditions in the individual shop. To keep lot sizes up to proper quantity and quality, a certain overrun is usually desirable.

METHOD OF ESTIMATING MATERIAL FOR A CAST IRON BED PLATE.—Fig. 37 shows the finished surfaces of the bed plate, size 10 x 6 x 4 in., with four ½-in. holes drilled all the way through, and a smooth base. How much material must be charged into the foundry cupola to finish completely 500 pieces in the machine shop?

Foundry experience gives a percentage loss, through cleaning, of 11%. The riser and gate allowance is 2% of the total weight. Allow ¼ in.

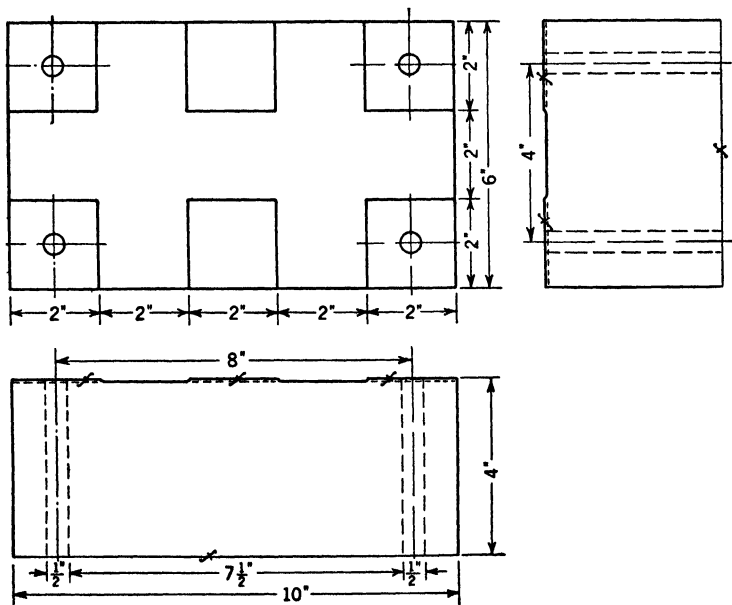



Fig. 37. Sketch of Cast Iron Bed Plate

stock for finishing the top surfaces and 1/8 in. for grinding the base. The problem is to find the weight of the finished product.

CALCULATIONS

First find the basic volume of the piece:

10″ × 6″ × 4″	240 cu. in.
To this must be added material for finishing:	
Top: 2″ × 2″ × 1/4″ × 6 surfaces	6
Bottom: 6″ × 10″ × 1/8″	7 5
Total	253.5 cu. in.
Material weight at this point is:	
253.5 × .2605 lb. per cu. in. (Fig. 10) = 66.04 lb. per piece	
66.04 × 500 = 33,020 lb. for 500 pieces	33,020.00 lb.
To which must be added the 11% loss in the foundry:	
33,020 × .11	3,633.20
	36,653.20
Riser and gate allowance is 2%:	
36,653.20 × .02	733.06
Final total weight in foundry	37,386.26 lb.
As a rounded figure	37,400 lb.

Finished product will weigh the nominal dimensions less the drilled holes:

Holes,
$\pi(1/2)^2 \times 4 \times 4 = 3.1416$ cu. in.
240 cu. in. − 3.14 cu. in. = 236.86 cu. in.

Weight of one piece,
236.86 × .2605 = 61.6 lb.
61.6 × 500 = 30,800 lb.

Difference between amount of metal put into cupola and that in finished parts, for an order of 500 pieces,
37,400 − 30,800 .... 6,600 lb.

(Values are in percentage of weight of cathode)

Cause	Cadmium	Chromium	Copper	Gold	Nickel	Silver
Shrinkage (cleaning tank)*	.0010	.0010	.0010	.0001	.0010	.0001
Plating holder*	.0050	.0050	.0050	.0010	.0050	.0010
Overplating (thickness)	.0050	.0050	.0050	.0001	.0050	.0001
Needless plating (inside of piece)	.0100 to 0500	.0000	.0200 to .0100	.0010	.0500 to .0200	.0010
Poor pre-cleaning†	.0050	.0050	.0050	.0000	.0050	.0000
Post-cleaning polishing†	.0010	.0010	.0010	.0000	.0010	.0000
Improper bath†	.0050	.0050	.0050	.0000	.0050	.0000
Improper voltage or amperage regulation	.0100	.0100	.0100	.0010	.0100	.0010
Adverse chemical reaction	.0050	.0050	.0050	.0000	.0050	.0000
Average total losses	.0470 0870	.0360	.0470 .0570	.0320	.0570 .0870	.0320

* Some material salvagable. † Can be corrected or remedied.

FIG. 38. Material Losses in Plating

METAL-PLATING MATERIALS.—In estimating materials to be used in plating it is almost impossible to forecast exactly for any one casting, forging, or machined part, because of the many variables involved. Some of the more common are thickness of the plate, strength of the solution, voltage and amperage used and their regulation, and such imponderables as overplating, pre- and post-cleaning, and the like. The usual method of determining the amount of material used and lost is: (1) calculate the area of the surface plated and the thickness of the plating job, (2) translate these data into pounds of material, and (3) compare the result with the quantity, in pounds, of plating material actually put into solution through the cathode. Fig. 38 gives approximate average losses for the more usual types of plating.

Estimating Nonmetallic Materials

ESTIMATING HARD RUBBER.—It is difficult to be definite concerning the estimating of hard rubber due to losses in casting or molding which, in turn, are due to the variety of design of the articles and to the production methods used. Compounds of hard rubber vary with almost every piece made. Certain generalities, however, can be made.

Molding losses range from 5% through 30%. These losses are due primarily to the overflow which must be allowed when figuring the amount of rubber to put into the mold. Rubber, as it is put into a mold, is not in the shape of the molded article. The wide range in percentage variation is due mostly to difference in design. A simple cylindrical piece would require a low percentage of overflow, while a more complicated piece would have a high percentage. Ordinarily, small articles have a larger percentage loss allowance than have the larger articles.

Vulcanizer losses are about ½ of 1%. These losses are due to free sulphur in the compound and to other gaseous elements in the chemical structure of the material.

Machine losses range from 3% through 17%. Hard rubber may be machined like any metal. Losses, however, range upward to a higher percentage. For example, in grinding a rough rod or tube to a finished size, if the rod or tube were of a relatively large diameter, say 3 or 4 in., about 3% would be required. If the rod or tube were of small diameter, however, say ⅛ in., about 17% would be required. This range covers other usual machine-shop operations. For cut-offs, use the same allowances as for metal rods.

PLASTICS.—As with hard rubber, the weight of material needed is calculated by volumetric formulas, to which the various losses due to machining must be added, and from which certain other losses, such as shrinkage, must be subtracted. The problem in plastics is complicated because of the innumerable compounds of this kind of material. Estimated shrinkage losses in various compounds range from a low of about .003 in. per inch to .015 in. per inch in all directions. In general, there is a smaller shrinkage if there is a higher asbestos content, if there is more filler, or if the compound has a higher heat resistance. While highly important in the processing of products from plastics, these shrinkage losses are too minor in amount to be taken care of as a separate factor in estimating the cost of jobs.

	Type	Trade Names	Typical Uses	Appearance	Tensile Strength	Toughness	Hardness	Rigidity	Resistant To: Water	Heat	Acids	Alkalies	Solvents
Thermosetting	Phenol (molded)	Bakelite, Colorsn, Durez, Durite, Haresite, Indur, Insurok, Makalot, Nellite, Resinox, Textolite, Uniplast	Electrical parts; housings; closures, wide variety of industrial, consumer applications Used as liquid in paint, paper, for bonding.	Restricted colors. Transparent, translucent, opaque.	X	X	X	X	X	X			X
Thermosetting	Phenol (cast)	Bakelite, Catalin, Gemstone, Marbiette, Opalon.	Housings, handles; lighting fixtures; novelties.	All colors Transparent, translucent, opaque.	X		X	X	X				X
Thermosetting	Urea	Bakelite U., Beetle, Plaskon.	Housings; closures; electrical devices; novelties; tableware.	All colors Translucent, opaque.	X		X	X	X	X			X
Thermoplastics	Acrylic	Acryloid, Crystalite, Lucite, Plexiglas.	Airplane windshields, turrets, noses, containers; lenses; frames, furniture, displays.	All colors. Transparent (crystal).				X	X				
Thermoplastics	Cellulose Acetate	Bakelite C.A., Fibestos, Lumarith, Nixonite, Plastacele, Tenite.	Auto and refrigerator hardware; pens, pencils, optical frames, panels, combs; novelties, phone bases; gas-mask lenses, brush handles	All colors. Transparent, translucent, opaque.		X							
Thermoplastics	Cellulose Acetate Butyrate	Tenite II.	Household, auto, refrigerator hardware, toothbrush handles; extruded trim, housings.	All colors. Transparent, translucent, opaque.		X			X				
Thermoplastics	Cellulose Nitrate	Celluloid, Nitron, Nixonoid, Pyralin.	Wide variety of consumer goods — novelties, knife and fork handles, rulers, toys, pens, pencils, optical frames, etc.	All colors. Transparent, translucent, opaque.	X	X			X				
Thermoplastics	Ethyl Cellulose	Ethocel.	Recordings, coatings; electrical insulation, combs; extruded shapes for furniture, architectural, decorative uses	All colors Transparent, translucent, opaque.		X						X	
Thermoplastics	Polystyrene	Bakelite P., Loalin, Lustron, Styron.	Electrical, radio, television equipment, trim, panels, containers; housings, refrigerator parts; closures, lenses, jewelry, combs.	All colors. Transparent (crystal).				X	X		X	X	
Thermoplastics	Vinyl	Alvar, Butacite, Butvar, Formvar, Gelva, Koroseal, Saflex, Saran, Vinal, Vinylite.	Filler in safety glass; coatings, linings, tape, dials, raincoats, belts; electrical insulation; containers; tubing; sheeting; seat covers.	All colors. Transparent, translucent, opaque.	X	X			X		X	X	

FIG. 39. Relative Properties of Plastic Materials

In molding, there are sometimes slight losses in handling and preforming the materials, and losses in fins and flashes, the total ranging from about 2% to 5%. These losses are taken into account in estimating.

Most thermosetting plastic scrap is valueless and cannot be reprocessed, for the material undergoes a permanent chemical change. Some of the scrap, however, may be used as filler and about 10% may be recovered in this way. It is better than wood flour from the standpoint of moisture resistance. As most plastic molding shops have more of this scrap than they can use, there is only a limited market for this material.

Thermoplastic scrap can be reused sometimes to the extent of 100% because it has been little affected in original properties by the processing. It may not be quite so flexible as new material and a little contamination sometimes affects the appearance of the products.

The electrical characteristics of plastics are important. Plastics are all good insulators. Polystyrene has a very low electrical loss characteristic at radio frequencies, approaching that of fused quartz.

These plastics stand up well in all machining operations with the range of losses the same as for hard rubber for all practical purposes. Fig. 39 gives certain relative properties of the more commonly used plastics.

Hard Wood*				Soft Wood*			
Name	Weight in Lb. per Cu. Ft.		Type	Name	Weight in Lb. per Cu. Ft.		Type
	Green	Dry			Green	Dry	
Alder	48	28	E	Cedar	27-56	23-29	E
Ash	48	41	H	Cypress	51	32	M
Aspen	43	26	H	Fir	36	31	M
Basswood	42	26	E	Hemlock	50	28	M
Beech	54	45	H	Larch	58	48	H
Birch	54	45	M	Pine	35-45	25-41	E
Butternut	46	27	E	Redwood	50	28	M
Cherry	45	35	H	Spruce	34	28	M
Chestnut	56	30	E	Tamarack	47	37	M
Cottonwood	49	28	M				
Elm	54	35	H				
Gum	50	34	M				
Hackberry	50	37	H				
Hickory	63	51	H				
Locust	61	50	H				
Magnolia	59	35	M				
Maple	45-46	33-44	H				
Oak	36-63	25-47	H				
Poplar	38	28	E				
Sugarberry	48	36	H				
Sycamore	52	34	M				
Walnut	58	38	M				

* The hard woods are usually the broad-leaved, while the soft woods are conifers. There is no definite degree of hardness which divides these varieties.

E = Easy to work. M = Medium to work. H = Hard to work.

Fig. 40. Weight of Wood from Native North American Trees

Direction	From Green to Oven-Dry Condition, % of green size	From Green to Air-Dry 12–15% Moisture Content, % of green size
Tangential	4.3 to 14.0	2.1 to 7.0
Radial	2.0 to 8.5	1.0 to 4.2
Longitudinal	.1 to .2	.05 to .1
Volumetric	7.0 to 21.0	3.5 to 10.5

Fig. 41. Shrinkage of Wood

Nominal Size	American Standard Dressed Size	Area of Section*	Weight per Ft.*	Nominal Size	American Standard Dressed Size	Area of Section*	Weight per Ft.*
In.	In.	Sq. In.	Lb.	In.	In.	Sq. In.	Lb.
2x 4	1⅝x 3⅝	5.89	1.64	10x10	9½x 9½	90.3	25.0
6	5⅝	9.14	2.54	12	11½	109	30.3
8	7½	12.2	3.39	14	13½	128	35.6
10	9½	15.4	4.29	16	15½	147	40.9
12	11½	18.7	5.19	18	17½	166	46.1
14	13½	21.9	6.09	20	19½	185	51.4
16	15½	25.2	6.99	22	21½	204	56.7
18	17½	28.4	7.90	24	23½	223	62.0
3x 4	2⅝x 3⅝	9.52	2.64	12x12	11½x11½	132	36.7
6	5⅝	14.8	4.10	14	13½	155	43.1
8	7½	19.7	5.47	16	15½	178	49.5
10	9½	24.9	6.93	18	17½	201	55.9
12	11½	30.2	8.39	20	19½	224	62.3
14	13½	35.4	9.84	22	21½	247	68.7
16	15½	40.7	11.3	24	23½	270	75.0
18	17½	45.9	12.8	14x14	13½x13½	182	50.6
4x 4	3⅝x 3⅝	13.1	3.65	16	15½	209	58.1
6	5⅝	20.4	5.66	18	17½	236	65.6
8	7½	27.2	7.55	20	19½	263	73.1
10	9½	34.4	9.57	22	21½	290	80.6
12	11½	41.7	11.6	24	23½	317	88.1
14	13½	48.9	13.6	16x16	15½x15½	240	66.7
16	15½	56.2	15.6	18	17½	271	75.3
18	17½	63.4	17.6	20	19½	302	83.9
6x 6	5½x 5½	30.3	8.40	22	21½	333	92.5
8	7½	41.3	11.4	24	23½	364	101.0
10	9½	52.3	14.5	18x18	17½x17½	306	85.0
12	11½	63.3	17.5	20	19½	341	94.8
14	13½	74.3	20.6	22	21½	376	105.0
16	15½	85.3	23.6	24	23½	411	114.0
18	17½	96.3	26.7	20x20	19½x19½	380	106.0
20	19½	107.3	29.8	22	21½	419	116.0
8x 8	7½x 7½	56.3	15.6	24	23½	458	127.0
10	9½	71.3	19.8	26	25½	497	138.0
12	11½	86.3	23.9	28	27½	536	149.0
14	13½	101.3	28.0	24x24	23½x23½	552	153.0
16	15½	116.3	32.0	26	25½	599	166.0
18	17½	131.3	36.4	28	27½	646	180.0
20	19½	146.3	40.6	30	29½	693	193.0
22	21½	161.3	44.8				

* Area of section and weights per ft. are given for dressed size only.
The weights are based upon assumed average weight of 40 lb. per cu. ft.

Fig. 42. American Standard Sizes of Timber

WOOD, TIMBER, OR LUMBER.—The problem of estimating wood as a material is complicated, despite the fact that shrinkage and weights are known and are very constant, because in many cases loss of material occurs through poor design. Designs which do not take into account standardized lengths are particularly the cause of most loss in these instances. Wood—timber or lumber—has been standardized according to size or weight of the green wood. Figs. 40, 41, and 42 give the weights and sizes of sections and shrinkage of green and dressed, hard and soft woods, and an indication of whether or not the wood is easy to work.

Fig. 43 shows a typical moisture shrinkage curve, both radial and tangential. Curves of this kind have been drawn for every type of wood. (Complete information can be found in publications of the National Lumber Manufacturers Assn. or in the Wood Handbook of the Federal Dept. of Agriculture.)

Most losses in wood arise from the fact that standard lengths have increments of 2 ft. up to 20 ft., and then increase by 4, 5, or 10 ft. In a design, if a span calls for 10 ft. 8 in., a 12-ft. length must be bought, from which 1 ft. 4 in. must be cut off. This small piece is often waste. The width of the cut-off tool in lumber is relatively the same as in metals and must be accounted for in the same manner. In modern timber construction the amount of waste has been considerably reduced, due primarily to use of metal in the connectors. Over-all percentages of waste range from 15% through 30% according to the care taken in the design. With proper recognition of standard sizes this waste may be cut down to about 5%. Timber for concrete forms usually can be used only three times. After the third use it is waste; there is little market for any wood waste.

PHARMACEUTICALS.—Estimating materials in the drug and pharmaceutical industry is done entirely by chemical formulas. Quality of goods produced is dependent upon the care taken in mixing the formula, and in the material which has been purchased. Because of the high standards demanded by law, and to eliminate error in transcription, certain pharmaceutical houses do not copy the formula when sending it into production. The original formula is photostated to prevent human error. This original formula is kept safely locked up as a master record.

Summaries of Job Costs

MATERIALS COSTS.—In estimating the cost of materials for a job, the estimator, besides making allowances for scrap, waste, spoilage, and losses of the kind elaborated upon in the previous discussion, must exercise good judgment as to the use of present inventory prices or market prices, or probable future prices if the job is to be made in the future.

Fig. 44 is a detailed materials estimate form which indicates the routine of calculating the cost of material to be used on the center bracket of Fig. 1. All of the elements of cost entering into the material should be recorded on a form showing the amount of material in the finished product, the amount of scrap, waste, and spoilage, and the price of the material, whether it is priced at inventory, market, or contract prices.

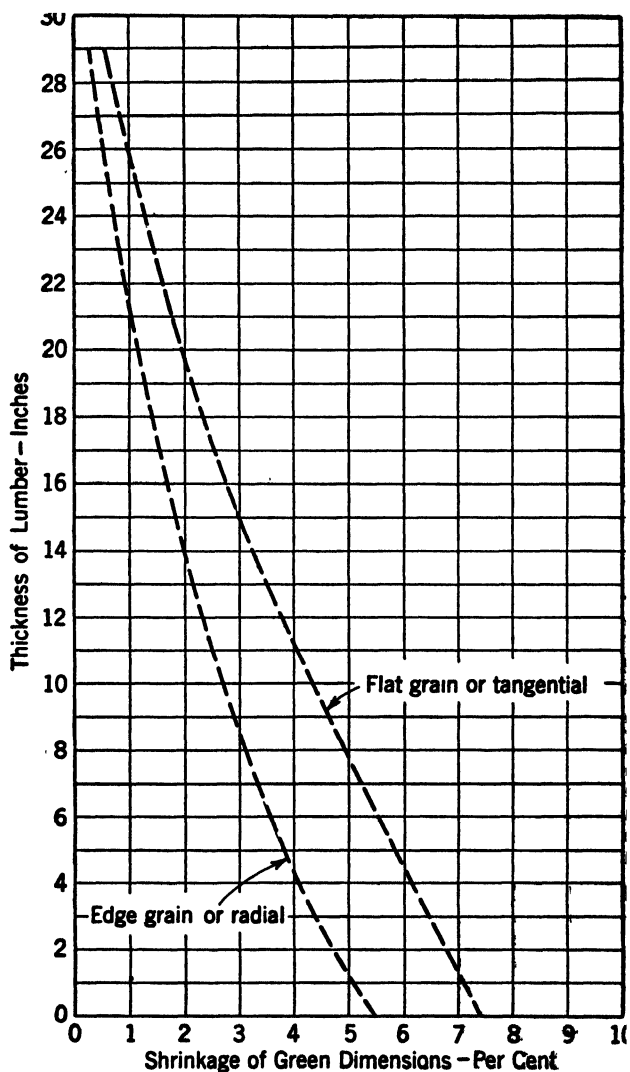



FIG. 43. Typical Moisture Shrinkage Curve: Douglas Fir—Southern Yellow Pine (Shrinkage in per cent of green dimensions)

DETAILED MATERIAL COST ESTIMATE DATE JAN 1, 19– NO 12345

CUSTOMER MECHANICAL PRODUCTS COMPANY DRAWING NO 6613

PART NO 6789 DESCRIPTION END BRACKET

USED ON ASSEMBLY NO 67 DESCRIPTION TYPE "A" BURNER

KIND OF MATERIAL 1/8 C R STRIP STEEL 5" WIDE

QUANTITY IN FINISHED PRODUCT	80 LBS	PER M PARTS
SPOILAGE	4 LBS	" " "
WASTE	5 LBS	" " "
TOTAL QUANTITY REQUIRED	89 LBS	" " "

PRICE ~~INVENTORY~~ ____ PER ____

" MARKET .09 PER LB COST PER M PARTS $8.01

" ~~CONTRACT~~ ____ PER ____

REMARKS ____________________

ESTIMATED BY ____________

FIG. 44. Detailed Material Cost Estimate

etc., so that the final result will show the total cost of the material in the part or product.

OVERHEAD.—In estimating the cost of mechanical products, overhead must be included as well as labor and material. The particular method of applying overhead charges depends upon the system in use in the individual plant, but the same method should be used in job estimates as is used in the manufacturer's cost system. This plan will enable the job estimator and the cost department to compare estimates with actual costs and thereby to set up relative standard costs.

ESTIMATED COST SUMMARY.—A form for summarizing the costs of labor, material, and overhead is shown in Fig. 45, a cost summary. If it is necessary to calculate the estimated cost of several parts making up a complete unit or assembly, the detailed labor cost of each part should be made on a form similar to Fig. 1, and the cost of material required on a form similar to Fig. 44. The total costs for labor and material should then be summarized on a cost summary sheet, similar to that shown in Fig. 45.

The cost of tools required for the job, if new tools are necessary and are to be built especially for it, should be calculated on sheets in the same detail as for labor and materials. The total cost will then be summarized on Fig. 45, with the total tooling cost shown on one line,

ESTIMATED COST SUMMARY

DATE JAN. 1, 19— NO. 12345

CUSTOMER MECHANICAL PRODUCTS CO.

ASSEMBLY DRWG. NO. 6622

PART NO. 67 DESCRIPTION TYPE 'A' BURNER COST PER M PARTS

ON BASIS OF 500 "

PART NO.	ESTIMATE NO.	DESCRIPTION	NO OF PARTS	LABOR		MATERIAL	PRIME COST	OVERHEAD		TOTAL COST
				SETUP	OPERATION			ON SETUP	ON OPERATIONS	
6789	12345	CENTER BRACKET	500	2 35	18 07	8 01	28 43	3 67	26 62	58 72
COST OF PARTS										
ASSEMBLY LABOR										
TOOL COSTS										
TOTAL COSTS										

ESTIMATED BY ____________

FIG. 45. Estimated Cost Summary

or columns added for such costs if calculated for several different parts, and will show the number of pieces covered by the estimate, cost of the set-up labor, cost of operating labor per piece or per thousand pieces, material cost (each or per thousand), and total material and labor cost shown under the column marked "Prime Cost." The overhead cost is also shown, divided into set-up overhead and operating overhead, and the total of all these items makes up the cost of the article. A summary made in this style will make the task of pricing easier for the persons setting the selling prices, as they will have before them, at all times, the amounts of the different elements making up the estimated cost.

It may be advantageous to try to sell to a customer 1,000 articles instead of 500, if the set-up time and tool cost are out of proportion to the labor cost. It may be necessary, owing to competition, to figure very closely on jobs, and in this case the price setter may want to know how much overhead is included in the costs. The tool cost is shown separately in the summary because it may be advantageous to speculate on the possibility of using the tools not only for the immediate requirements, but for estimated future requirements as well. In such a case, a lower price may be quoted on the order.

The job estimator should give special attention to machining cycles or the time necessary for a machine, requiring attendant labor, to per-

Product Name Cast Iron Bed Plate		Date Nov. 12, 19—	
Raw Material (Direct)..............At $1.00 per lb.	$ 73.31		
Raw Material (Indirect)			
Bar Stock			
Castings and/or Forgings			
Purchased Parts (Semi-Finished)			
Purchased Parts (Finished)			
Assembly Material		$ 73.31	
Total Material			$ 73.31
Direct Material Handling, Storage, etc. ....15% of wt. cost	11.00		
Direct Material Handling, Storage Overhead ....10% of wt. cost	7.33	18.33	
Total Direct Material Manufacturing Cost......			91.64
Direct Labor (See dept. estimates) ....All departments	12.25		
Direct Labor Overhead (See dept. estimates) ....All departments	5 25	17.50	
Total Manufacturing Cost......................			109.14
Administrative, Sales and Service ....100% of mfg. cost	109.14		
Engineering, Experimental, Tools.. 50% of mfg. cost	54.57		
Plant Maintenance and/or Protection .... 50% of mfg. cost	54.57	218.28	
Total Actual Cost			327.42
Profit ....20% of Actual Cost	65.48		
Royalties		65.48	
Selling Price			392.90

Fig. 46. Selling Price Estimate Sheet

form its operations. It may be cheaper for one operator to operate two machines with two sets of tools, than to have one operator operate one machine with one set of tools. Furthermore, consideration must be given as to whether or not it would be better, for example, to operate one machine with one set of tools, double shift—one operator on a regular shift, and another on an overtime shift—even if a bonus or extra pay must be given for this overtime.

SELLING PRICE ESTIMATE SHEET.—In estimating the selling price, there are several other items to be added to the estimated cost. These items are illustrated in Fig. 46 for the cast iron bed plate shown in Fig. 37. The following data are taken from this example, and on the basis of these data the completed estimated selling price sheet is filled out.

Machined weight per piece	61.60 lb.
Foundry weight per piece	66.04
11% loss in foundry per piece	7.27
Total material weight per piece	73.31

Factors in Setting Sales Prices.—In fixing the selling prices of mechanical products, consideration should be given to whether or not the article is competitive or is covered by patents. Unless they have some points which make them more valuable to customers, articles must be priced at competitive prices in order to sell in the market. When articles have been patented, it should be considered whether the prices are so high that other less expensive but not so satisfactory articles may be attractive to prospective customers. When considering competitive prices, the price setter must know whether or not similar articles are being sold at so-called "cut-throat" prices rather than at fair prices. It may be that competitors may quote prices on merchandise at a loss in order to eliminate other manufacturers from the market. The price setter must also estimate the various volumes of merchandise which can be sold at various prices. The price must not be set so high as to discourage the demand.

SECTION 16

JOB EVALUATION

CONTENTS

Operation of a Job Evaluation Plan

SECTION 16

JOB EVALUATION

BASIS OF WAGES.—Basically, wages are determined by the law of supply and demand. A shortage of a particular type of skill makes it possible for workers in that field to demand and get higher wages, and an oversupply of labor results in lower wages, unemployment, or both. In any one locality, however, wages paid for a certain skill will show some variation depending on the wage policies of each employer. In general, the most profitable firms will pay the highest wages, and marginal firms the lowest.

Natural Minimum Rates.—The natural minimum rates payable by any firm, that is, the lowest rates which are not directly affected by legal mandate, approximate the lowest rates current in the local labor market. Lower rates than these result in employee indifference, turnover, and inadequate supply. A company can pay higher than average rates if, through good management, its employees can, and do, work at above-average efficiency. A firm earning an unusually good profit does not necessarily have to pay higher than average wage rates, but may choose to do so to assure an adequate labor market from which it can select the best workers. Accelerating consumer demand and consequent widening of profit margins induce business to expand and hire more labor, which ultimately results in an undersupply of labor and an increase in wage rates. On the other hand, a slackening of consumer demand results in curtailment of operations, an oversupply of labor, and ultimately in lower rates. Neither employers nor employees can for long resist a general price movement. (For a review of wage theories, see Douglas, Theory of Wages.)

General Wage Levels and Differentials.—There is a difference between the level of wages and differentials existing among jobs within a company or within a labor-market area, and also a differentiation between the lowest rate paid for the lowest grade job and the level of wages. The natural minimum rate might be the same among a number of companies but the general level of rates may vary in each company. Therefore, while the minimum rate might be nearly equal in all companies, the general level of rates may vary among the companies in accordance with the difficulties of the jobs and the rates paid. (Samuel L. H. Burk, Chief Job Analyst, The Atlantic Refining Co.)

Rates for Intermittent Work.—Irregular workers, such as building craftsmen, should be paid hourly rates high enough so that their net

yearly earnings are about the same as those of full-time workers. Conversely, factory carpenters, painters, and others who have full-time employment can be paid rates comparable to other factory workers and lower than regular building craftsmen on irregular work.

Adjustment of Rates to Cost of Living.—During the First World War many English and a few American companies used a cost of living index, or "sliding scale," as a means of automatically readjusting wage rates. In England these plans were generally arranged between the employer's association of a whole industry and the trade union; in America they were initiated by owners of individual companies and the index was made to reflect the local changes. For a decade or more this practice did not get far in the United States because prices, 1923 to 1929, were practically stable and need for such adjustment disappeared. By 1936, however, governmental arbitration boards had come to use such indices considerably, and the General Electric Co., among others, decided to make a permanent arrangement which would be automatic. Regular publication of indices by Bureau of Labor Statistics (22 cities), National Industrial Conference Board (56 cities), Massachusetts Department of Labor and Industries, and the Michigan Department of Labor and Industry, makes it relatively easy for many companies to make these adjustments. There are two dangers in such a plan. Statisticians do not agree on how the index should be made. Hence there may be lack of confidence that the index truly reflects actual cost of living. Even when the index is approved there remains dislike of sudden or frequent revisions downward. If the plan is to be used it should be carefully worked out, reasonable warning time allowed, and the principle completely "sold" to labor.

Examples of Adjustment to Cost of Living.—The General Electric Co.'s plan applied to all hourly rated employees and those on salary up to and including $4,000 per year. United States Department of Labor indices were used. For each point change of the indices above 80, a 1% rate change became automatically effective. The actual change was made when the index passed the half point, that is, from 80.5 to 81.4 the rates became 101% of the original bases, and from 82.5 to 83.4 the rates were 103%, etc. These adjustments were calculated weekly on the gross basic earnings. A maximum 10% was fixed as the top rate limit, and the basic rates at time of the agreement were fixed as the low rate limits. No commitments were made as to future changes beyond these limits. In the fall of 1941 the plan was discontinued because of war conditions.

The International Ladies Garment Workers' Union has put the following plan into some of its **agreements for piece- and time-rate workers.** Whenever the United States Department of Labor indices show a change equal to or exceeding 5%, the rates shall be changed by the same percentage but made effective one month after publication of the indices.

A public utility company applied the same indices to all employees earning less than $250 a month but figured on amounts less than $125. Adjustments were made only twice a year, January and July, if the change exceeded 3 points relative to the ones last used. Employees within each wage classification received the same adjustment, which was calculated to the nearest one-half cent for hourly workers, and to the nearest 50 cents for salaried workers.

Wage Rates

BASE RATES.—The hourly rate established for the least valuable work in a community is called the fundamental base rate. This rate is set by supply and demand and is less local than other rates because of "fluidity" of unskilled workers. In general, however, the regional cost of living becomes the lower limit of this rate (Monthly Labor Rev., vols. 46, 47). Base rates for all other jobs are the prevailing rates for fulfilment of minimum requirements of each job class. These classes range through various degrees of semi-skilled and skilled work, some of which are in the nature of "key-jobs," and may be compared as to their "going-rates." Base rates for job classes, or labor grades, which include no dependable key-jobs must be independently evaluated or interpolated relative to known base rates of classes which do include key-jobs. In order to facilitate shifting back and forth between hour-rate jobs and piece-rate jobs it has usually been desirable to establish a **base hourly rate** for each piece-rate operation or other incentive-paid operation.

This base should be derived like that of any time-rate job and should be used for the time-rate portion, if any, of the incentive plan. The **rate per piece**, however, may be figured backwards from the average total earnings per hour, say over the previous month. Where piece payment or other incentive plan is backed by a time guarantee for **management delays** only, the rate for that is often set at 80% of the worker's average earnings per hour during the previous four weeks. This basis is justified by the experience that incentive workers usually produce 10% to 20% more than nonincentive workers, production standards having been carefully established in both instances, and, at 80% of their accustomed earnings, will be at par with the latter.

Perhaps for this temporary use such an arbitrary arrangement is good enough, but even if the 80% figure is equivalent to the derived rate, it is preferable to derive the guarantee, that is, use a reliable base. If this is done the rate per piece can be built above it. The guaranteed rate exists to protect the incentive worker against any lack of opportunity to continue on incentive work. If, on the other hand, a foreman wishes him to do a nonincentive job temporarily as an aid to management, the hourly rate for such work should equal the full average of the worker's incentive earning. If such special services are regularly demanded, a management may grant the worker an hourly rate slightly above his former average. This is called a **versatility rate,** that is, the individual is paid extra because he is able and willing to work at various jobs on demand.

As to **hiring rate,** it is best practice to hire at the regular base rate. Some companies have tried to start at 80% of base but since the evaluated base rate is worked out on minimum requirements, anything less than 100% of it is conspicuously unjust, except for a learning period, and puts the company at a disadvantage in the labor market. Use of low rates as bases for bonuses still survives where an employer thinks he can thereby magnify his bonus. Some employers deliberately set their base rates low and have a correspondingly higher bonus percentage.

RATES FOR NIGHT SHIFT.—Extra differentials for night and Sunday shifts are usually matters for union negotiation and have some-

times been forced to high amounts. Without such necessity it is common to increase these rates by some percentage (10 to 33), usually to the same degree for all jobs. Many companies prefer to keep base rates the same for all shifts and add a bonus percentage or add a flat increase for the second and third shifts. Where the various shifts are permanent and the personnel rotated from one to the other it may be possible to maintain the same rates for all shifts, but where eight-hour shifts are used it is impossible to have shifts of equal desirability and some differential is usually necessary. Where six-hour shifts are used no extra differentials are needed.

APPRENTICESHIP RATES.—The original idea that an apprentice to a skilled trade should pay for the privilege of learning, rather than be paid for it, has all but disappeared. He is usually older when he starts than formerly, and rarely now does he receive "lodging with board" as compensation. Furthermore, under modern conditions, from almost the start he can be productive despite costs of instruction and other kinds of burden charged against him. Since 1938 the Fair Labor Standards Act has fixed the lower limit of pay. (Wage and Hour Manual, issued annually to answer questions of interpretation.) "The Administrator . . . shall by regulation or by orders provide for (1) the employment of learners or apprentices, . . . under special certificates issued pursuant to regulations of the Administrator, at such wages lower than the minimum wage applicable under Section 6, and subject to such limitations as to time, number, proportion and length of service as the Administrator shall prescribe, . . ." Actually these bottom rates vary considerably according to location and kind of trade.

Usually the length of the whole apprenticeship is divided into about eight periods and a rising scale of rates set up to change at the end of each period. On a four-year average these rates amount to a little more than half of the rates paid to fully skilled workers in the same trades. In fact, some companies set up the learner's rates in terms of per cent so that the apprentice will be automatically kept in adjustment to the skilled workers, and in line to achieve the regular base rate at the end of apprenticeship. There is, of course, an incentive problem involved, and the increments may not be equal throughout the periods.

OVERTIME RATES.—The practice of paying **time and a half** for overtime, made common by the War Labor Board in 1917–1918 (Am. Econ. Rev., vol. 29), has now become mandatory through the Fair Labor Standards Act. Section 7 of the act specified such payment "at a rate not less than one and one-half times the regular rate at which he (employee) is employed" for each hour of work in any work week in excess of 40 hours per week. Interpretation of the board is that any bonus which is in the nature of a production bonus, or premium, must be included in the base upon which an employee's regular rate is computed. **Gratuities** not in nature of a contract right such as Christmas "bonuses" may be excluded. Similarly a **profit-sharing "bonus"** which is given at the discretion of an employer, that is, with no legal right of anticipation either expressed or implied, may be excluded. But if a bonus is promised at the end of the year contingent on **performance** it must be included. As soon as the amount of such annual bonus may be calculated it should be apportioned over the hours covered by the period and over-

time rates for each particular week corrected. Averaging of other compensation or hours over two or more weeks is not permitted for overtime calculations (Interpretive Bul. 4).

Payment of an annual bonus was, until 1938, becoming increasingly common. If wage rates are at or above the market average these bonuses have a good effect on employee goodwill. If wage rates are below market, employees will consider them merely as overdue wages. In any case, since 1938, the delayed nature of these arrangements has imposed great difficulties and is causing some companies to cancel them.

New Basis for Rate Setting

INFORMAL RATE SETTING NO LONGER ADEQUATE.—Job standardization, that is, motion and time study, resulted directly from the developments of Taylor and Gilbreth, with the objective of determining the most expedient method of doing each job and establishing work standards as dependable bases for tasks. This "science of work," plus a narrower functionalization of duties and a more careful selection of high-class workers, pointed the way toward present-day job evaluation, but the latter did not develop immediately or directly from industrial engineering. It came from personnel executives who needed to collect job information as an aid to hiring and placement (Griffenhagen, A.M.A. Off. Exec. Ser. 17). Thus the **"job analysis"** of 1909–1917 began job study at the point where engineers had ended, with the objective of determining job characteristics in relation to man-qualifications necessary for operating according to standards, and making a rate structure which would bring economic satisfaction to all concerned. The First World War gave impetus to this personnel function (Natl. Assn. of Corporation Schools, Convention Report 1919). In banks and insurance companies where there were large forces of stenographers, clerks, etc, it assumed the form of **salary standardization** (Hopf, S. I. E., 1921).

GROWING INFLUENCE OF LABOR.—Use of job analysis to determine rates systematically did not get far in factories during the 1920's, because the tendency was toward incentive payment where base rates were then considered incidental. Organized labor, however, had long advocated "standard wages" and numerous states passed **minimum wage laws.** The National Industrial Recovery Act of 1933–1935 put the latter on a federal scale, and the National Labor Relations Act of 1935 intensified the activity of the unions. After the Supreme Court sustained that law in 1937 the two-year-old Committee of Industrial Organizations was able to increase its membership by large numbers of unskilled and semi-skilled workers and exert a power never before wielded by American employees. Wage rates for large groups were set by collective bargaining and frequently pushed upward. Hours came down and, in not a few cases, efficiency per man-hour fell off alarmingly. Bargaining became as unbalanced in favor of employees as it had ever been unbalanced in favor of employers, and better substantiation of employers' claims became a pressing need.

At the same time, rapidly improving mechanization plus a widening use of **motion study** had been changing job methods so radically and

frequently that few jobs in one plant remained exactly like similarly titled jobs in any other plant. Employers could use only the relatively few key-jobs for rate comparisons; even these needed to be checked by personal inspection. Thus the going rate for any class of jobs in a community became less evident, and more undependable, as a basis for informal rate setting. As a result the management of each plant had to work out its rate structure somewhat independently of interplant comparisons.

The situation just presented would have been sufficient reason for perfecting the step of job evaluation, but the sudden, widespread interest it evoked resulted from the **union development** previously described. Feeling increased power, the union leaders in 1937 began to raise such questions as, "Why has Job A been paying five cents an hour less than Job B?" Sometimes they displayed more accurate knowledge of the jobs in question than management possessed. In such a predicament the management turned to the personnel department for data. Where job analysis, classification, description-specification, and evaluation had been well done, an answer could be given at once which would sustain any variance and forestall embarrassment. Sometimes there was qualitative but little quantitative data. Often there was neither. The few plants which had pioneered in systematic job evaluation soon acquired renown among the less foresighted.

Job Studies

JOB CONTROL AS A WHOLE.—The setting up and control of a job involves five or six major steps (Lytle, Personnel, vol. 16) each of which may be carried out independently and by different staffs. The steps are, however, sequential and for best results should be coordinated both in plan and in execution.

Major Steps in Job Studies.—The major steps necessary in studying jobs and establishing controls are as follows:

1. **Invention and Construction**—including development, design, and production of equipment, jigs, tools, gages, and auxiliaries. This step obviously belongs to the technical mechanical engineer.

2. **Job Standardization**—including development and standardization of most expedient arrangements, motions and times for utilizing the items of step 1 in producing goods or services. This step belongs to the industrial engineer.

3. **Job Review and Analysis**—including collection of data regarding job requirements, and the job "analysis," classification, and description-specification, that accompany the progressive stages. This step belongs to the personnel staff but in its modern expanded form, which seeks out the basic job characteristics and attempts to grade them in relation to employee minimum qualifications, it is highly desirable that the industrial engineer and supervisor should also participate usually as members of a committee.

4. **Job Evaluation**—applying rate setting to the above grades or, in its more scientific form, including the weighting of job characteristics as

to their relative importance in each job and fixing of base rates to correspond. This step is a continuation of the previous one and is done by the same committee. Final rates must usually be authorized by a line officer.

5. **Merit Rating**—including the systematic determination of employee relative merit on various man characteristics pertinent to the jobs involved. It is the means of recognizing the extra worth of certain time-rate employees and is the basis of determining individual differentials above the base rates. This step belongs to the personnel staff, but, as above, the recommended rates must usually be authorized by a line officer.

6. **Incentives**—including establishment of nonfinancial and extra-financial incentives to elicit optimum employee response, and to reward according to advance arrangements. This step might logically belong to the personnel staff but it was developed by the industrial engineers, and has not been coveted by other groups. There should be cooperation between groups, however, so that no human or psychological aspect will be overlooked. The scope of this section includes only major steps 3 and 4.

STUDY OF JOB AFTER ITS STANDARDIZATION.—After a job has been improved and standardized (step 2) two further procedures are necessary to bring it into an operating success. A job study must be made (step 3) from the viewpoint of the personnel department to assist selection, hiring, and placement or promotion of the desired operator at his proper rate (step 4). There must be a decision regarding method of remuneration. If the remuneration is to be by means of an extra-financial incentive plan, that plan must be designed and installed (step 6). A **base rate** in such case is often derived by working back from whatever total carning is found necessary for the desired average man-productivity, but it should be derived by regular evaluation. If remuneration is to be by means of an hourly rate, a base rate in such case must be determined which will attract an adequate supply of the right kind of operatives without upsetting the satisfaction of operatives on other jobs. This procedure, formerly known as **rate setting**, in its more systematic form is now known as **job evaluation.** Evaluation in terms of money, that is, actual rate setting, is the last act in step 4. The first act, a part of step 3, above, is called job review.

DETAILS OF JOB REVIEW, ANALYSIS AND CLASSIFICATION.—The successive procedures in step 3, Job Review and Analysis, are three in number—job review, job analysis, and job classification.

Job review is the collecting of the tentative descriptions of a job, preferably after standardization, in terms of the characteristics which may affect the kind of person needed to fill it, and conditions which may independently affect the rate of pay needed for filling it.

These tentative descriptions are gathered through questionnaire forms and/or through interviews recorded on suitable forms. They should be drawn from several of tha best operatives and the resulting claims checked by the safety man, maintenance man, inspector, and supervisor concerned. Fig. 1 is a specimen form (Burk, Personnel, vol. 15).

Job analysis is the critical analysis and selective synthesis of the data derived through job review, and recording of findings to show the kind

INTERVIEWER'S ROUGH NOTE SHEET

Job Title .... Other Titles .... Dept & Location .... Normal Force ....

Empl. Name .... Immed Supervisor .... Time on This Job; Company .... Elsewhere ....

Equip. Used .... Tools Used .... Materials Used ....

....

....

Work Rec'd From .... With What Instructions ....

Duties ....

(Use Other Side If Necessary) ....

....

....

Work Goes To .... Describe Checks, Inspections, Etc. ....

Contacts With Others ....

Hours Regular, From ......To ......Sunday, From ......To ......Shift ....Hours Overtime Per Mo. ....

Comments on Work. Cond.: Atmos. ....Temperature ....Ventilation ....

Surroundings ....Activity ....Hazards ....

Illumination ....Other ....

Exercises Supervision. Normal Force ....Type(s) of Work ....

Equipment Respons. ....Material Respons. ....

Opinions on Starting Requirements:

Age—Min. ....Male .... Married ......Height—Min. .... Wt.—Min. ....

Max. ...Female ....Single .... Max. .... Max. ......

Misc. Remarks:

Special Physical ....

Education: Gr. 1 2 3 4 5 6 7 8 High 1 2 3 4 College 1 2 3 4

Other Educ. ....

Experience: Necessary ......Years of ....

Desirable ......Years of ....

Special Knowledge or Ability ....

Time for New Emp. to Become Proficient ....

Promote From .... Promote To ....

Worker: Fluent.. Average.. Could Not Express Thoughts.. | Interviewer

Bright .. Intelligent .. Aver. .. Dull ..

Satisfactory Interview? | Date

Fig. 1. Interviewer's Note Sheet

and degree of duties, skills, exertion, responsibilities, conditions, etc., which belong to a specific job, all expressed as minimum man-qualifications. The resulting record is known as the **standard job description-specification.**

Job classification is the sorting of standard job description-specifications into a relatively small number of classes, each of which includes all jobs, and only those, which are identical or equivalent in essential characteristics, that is, in level of responsibility, degree of skill, etc. Subclasses may be necessary to accommodate variations in kind on each level.

JOB CLASSIFICATION PROCEDURE.—The procedure for job classification is (Palmer, A. M. A. Prod. Ser. 36):

1. **Standardize classification outline** or schematic arrangement which will set broad occupational divisions, and under them narrower occupational groups and individual "classes" of jobs, arranged according to series of classes, coming within each occupational group.

2. **Standardize class specifications** (or occupational specifications) each to show:

a. Class title to be applied to the class and to all jobs in the class.
b. Job-class description of duties common to all jobs of the class supported by typical examples as illustrating kinds of work falling within each general description, chosen from actual cases, to support and amplify these general statements of duties.
c. An enumeration of qualifications required, which may be grouped into two parts: necessary qualifications, and desirable additional qualifications.
d. Notes regarding lines of promotion, preferably in the form of a schedule of positions considered next higher in rank, and positions considered next lower in rank.
e. Notes regarding compensation if there is a compensation plan in effect.
f. Other facts, rulings, or memoranda that relate to the class and have a bearing on administrative processes in personnel matters.

3. **Standardize rules of administration** presenting clearly, and in logical order, principles and methods by which the classification plan is to be devised, adopted, applied, and amended; by which new and changed positions are to find their places under the classification outline; by which specifications are to be constructed, employed, and perfected; and by which employment processes are to be controlled or related to this basic plan and its system of nomenclature.

Symbols, such as A, B, C, etc., may be given to **standardized classes,** and subclasses may be shown as A_1, B_1, C_1, etc. Another method of symbolizing is to make numbers represent levels, and letters represent functional nature within a level. This plan is illustrated by Fig. 2 and the following example (A. M. A. Off. Mgt. Ser. 55):

Boiler Engineer	4A	Stoker Operator	6
Water Tender	4B	Boiler Cleaner	6
Pumpman	5	Ashman	7

For most applications the eight levels in Fig. 2 will need to be expanded, or accommodated by additional subdivisions.

GRADES AND SUB-GRADES

EXECUTIVE SERVICE
STAFF OR ADVISORY SERVICE
SUPERVISORY SERVICE
ROUTINE SERVICE

1. *General Management:* Establishes general procedure, organizes and directs the enterprise as a whole; makes decisions of general scope; adjusts relations with investors, the public and the personnel. (President, Vice President, General Manager, etc.)
A B C

2. *Departmental and Associate Management:* Establishes, organizes and directs procedure of major departmental scope or of inter-departmental scope but specialized or limited as to function—administration of a major department or subdivision of the organization, original investigation or research, invention, composition of data for informational and advisory purposes in general or major departmental administration. (Managers of departments and principal subdivisions, higher executive and staff assistants or their equivalents.)
A B C D E

I. *Management* — Formulation and development of general procedure and courses of action or policies, involving original observations, analyses, the establishing of standards, etc.; the original planning, organizing and executing of operations.

3. *Major Supervision or Highly Technical Service:* Execution of intricate operating practice by delegating activities and giving general directions to others in diverse occupations, depending upon their knowledge and experience for the performance of the tasks involved; observation and judgment of high order, involving the application of standards and analyses of established character; or, directly performing activities of a highly technical character but essentially established by higher authority and experience; resourceful application of courses of action. (Intermediate subdivision chiefs, technical assistants, superintendents, foremen, etc.)
A B

4. *Highly Skilled Service or Minor Supervision:* Service involving observation and judgment of high order with the application of standards and analyses of established character, and intricate, complicated or exacting details dictated by authority and long experience, subject to general supervision only—necessitating at least several years' experience in training; or supervision of others in work of less technical character but requiring some degree of skill.
A B

5. *Skilled Service:* Service with features as in the next higher grade but less intricate and exacting and subject to more supervision, necessitating experience of from one to two years in training; may include detailed direction of others in service of lower grade.

6. *Semi-skilled Service:* Routine work of limited scope requiring only short periods of experience or training (several months: for its successful performance, may include detailed direction of others in service of lower grade.

7. *Slightly Skilled Service:* Tasks of simple character requiring only simple observations and responses with little learning and experience for their successful performance—subject to close direction.

8. *Primary Service:* Tasks and routine of very simple character such as may be performed by junior workers, workers in early apprenticeship or similar elementary training and workers in manual service of simplest character.

II. *Operating Practice*—Supervision of or the direct performance of activities essentially established by authority, instruction or direct experience.

FIG. 2. Classification Plan for Grading Positions

JOB-CLASS DESCRIPTION-SPECIFICATION.—A job-class description-specification is a composite of all the standard job description-specifications within one class, or subclass, omitting any variations within the group. It is invaluable as an aid to hiring, transferring, and promoting.

Three kinds of description-specification are used:

1. The essay, which is primarily a descriptive statement. Mostly used for salaried employees. (See Fig. 3.)

RELATED EXPERIENCE	OCCUPATION	DESCRIPTION	NO. EMP.		SALARY RATES			AVERAGE LENGTH SERVICE
			M.	W.	Max.	Min	Avg.	
		ACCOUNTING — COST						
3 to 5 Years	Cost Clerk E-4	Sr. Compile complete factory cost of assemblies or finished products, from specifications, bills of material, requisitions and time cards, without detailed supervision. Verify costs on new products. Compare standard cost with actual cost. May involve preparation of necessary cost data for control of operations. Requires practical knowledge of products, manufacturing processes and procedures.						
12 to 18 Months	C-3	Jr. Compile factory costs on parts and assemblies following definite prescribed instructions under close supervision. Other junior clerical work as may be assigned.						
5 Years and Over	Cost Estimator F-2	Sr. Compile estimates of cost on standard and special parts or products, as a basis for pricing purposes. Should have engineering knowledge and be able to interpret engineering layouts and data. Requires extensive knowledge of products, designs, manufacturing processes and procedures.						
1 to 3 Years	D-1	Jr. Compile cost estimates on standard parts and assemblies working from positive information						

FIG. 3. Specimen Job Descriptions
(A. M. A. Off. Mgt. Ser. 84)

2. **The standard form** which is characterized by a list of items to be checked but with little or no space for description of the job or its requirements. (See Fig. 4.) This is a pioneer form.
3. **The combination of the standard form with complete descriptive statements** about different aspects of the job. Various combinations of essay and standard forms types have been developed. (See Figs. 13, 14a, and 14b.)

As implied in item 2 above, discussing the kinds of description-specifications, Fig. 4 has no space for description of the job or its requirements, and is thus really a job-specification plus a check-list description of the working conditions. In practice some space should be provided for a description of duties.

NATURE AND CONDITIONS OF WORK (Use [X] to indicate; [XX] to stress; or indicate percentage, e.g. [%] %)

Place: □ Outdoor □ Indoor □ Platform □ Overhead □ Underground □ Scaffold □ Pit □ Unlocalized
Type: □ Desk □ Bench □ Machine □ Counter
Activity: □ Standing □ Sitting □ Hauling □ Climbing □ Lifting □ Walking □
Operation: □ Repetitive □ Varied □ Automatic □ Semi-Automatic □ Much activity
□ Heavy □ Emergency □ Set-ups □ Layouts □ Templates □
Surroundings: □ Clean □ Dirty □ Greasy □ Gangwork □ Crowded □ Orderly □ Distractions
Instruction: □ Written □ Verbal
Illumination: □ Natural □ Artificial □ Excellent □ Good □ Fair □ Poor □ Glare
Atmosphere: □ Natural □ Ventilated □ Excellent □ Good □ Fair □ Poor □ Draughty □ Noxious Gas □ Fumes, odors □ Dust □ Very dry □ Humid □ Hot
Hazards: □ Fire □ Electricity □ Hernia □ Eyes □ Ears □ Lungs □ Violence □ Hands

Remarks: ....

Regular working hours; from ..... to ..... Sunday from ..... to ..... Shift ..... Hours overtime per month .....

REQUIREMENTS (Use X, XX, % or [R]—required; [P]—preferred)

Age: □ Max. □ Min.
Sex: □ Male □ Female
Marital state: □ Single □ Married
Color: □ White □ Black
Height: □ Max. □ Min.
Weight: □ Max. □ Min.
Intelligence (fifth): □ Highest □ Second □ Average □ Low □ Lowest
□ Bonded □ Color discrimination
Education—limits: Gr 0 1 2 3 4 5 6 7 8; High 1 2 3 4; Coll. 1 2 3 4
Kind.— ....
□ Contact with people
□ Add and subtract □ Multiply and divide □ Fract. and decimals □ Percentage □ Shop arithmetic □ Read blue prints □ Good handwriting
English: □ Understand □ Speak □ Read □ Write
Personal qualities: □ Unemotional □ Deliberate □ Quick □ Dynamic □ Tact □ Patience □ Fluency in conversation
Experience: Kind ....
□ Journeyman □ Apprentice □ Inexperienced

Special knowledge or experience ....

Remarks: ....

Date .... Name of Interviewer ....

FIG. 4. A Job Description-Specification

Job Evaluation Procedure

DEFINITION OF JOB EVALUATION.—Job evaluation is the ranking, grading, and/or weighting of essential work characteristics of all jobs or job classes in some systematic way to ascertain the labor worth of each job or job class relative to all others. Scientific evaluation is possible only when all of the foregoing steps 1 to 3 of job control have been standardized and carried out with unified control as objective. The example shown in Fig. 5 uses a conversion factor of 105%, meaning that all actual rates at that time had been increased 5% since the class base rates were first standardized (Personnel, vol. 15).

JOB EVALUATION BY RANKING OR GRADING.—Under the job ranking or grading plan, titles of all jobs are written on cards, and the cards are arranged in a series of job worth, each of which is known as a grade. The grading is done by several competent **judges** on the basis of the hourly rate which should be paid for each job, regardless of the present wage. The grades assigned to each job by all the judges are then averaged and this average is considered the "score" for that job. Hourly rates are then assigned to jobs in the order of their ranking, largely by arbitrarily deciding upon the rates to be paid highest and lowest jobs, and then seeking intermediate rates based upon the respective scores (see Fig. 5).

This plan is **weak** because (1) it is impossible to find many judges who are thoroughly familiar with all jobs being ranked, (2) present rates exercise an undue influence on the judges' minds, (3) the plan is based solely on opinions, and (4) judgments of equally competent graders frequently reveal such wide discrepancies that the averaging process becomes nothing more than a mathematical fiction (Benge, Ind. Rel., vol. 3). The extreme of this was "Predetermined Grading" in which all office jobs were arbitrarily classified into five to eight levels or grades, general specifications written for each grade, and salaries standardized accordingly.

BASIC EVALUATION OF AN OCCUPATION.—The basic evaluation should take into account only the inherent demands and characteristics of that occupation and should not include as a varying influence supply and demand, rates already in existence in the particular organization or in the general locality, or any other outside influence on the emolument rate. While it is recognized that such influences are definitely in existence and will no doubt effect final wage rates to some extent, they are not a part of the basic value of an occupation.

Who Should Make the Evaluation?—One important factor to consider when attempting a program of this kind is to determine who should do the work of making the evaluation. Selection depends upon circumstances involved, but it has been suggested that the most desirable individuals to establish such a comparative evaluation are those in the organization who control the employees who will eventually be affected by it, usually a committee composed of the supervisors of the hourly wage employees. One or more experienced "rate analysts," however, can save

JOB	POINTS						Base Class	Hrly. Rate at 1.05 Conv.
	Mental Effort	Skill	Phys. Effort	Respons-ibility	Work. Cond.	Total Points		
Toolmaker Leaderman (Working gang-pusher) (Daywork)	27	37	16	22	5	107	106	$1 11
Gyroscope & Marine Instrument Repairman (Daywork)	28	34	17	19	7	105	106	1.11
First Operator—Pipe Still Battery (Shift work)	24	24	16	24	14	102	103	1.08
Ethyl Blending Plant Operator (Daywork)	19	21	21	22	21	104	103	1.08
Toolmaker, Machine Shop (Daywork)	24	34	19	17	5	99	100	1.05
Bricklayer, 1st Class, Outside Plant (Daywork)	17	28	30	14	11	100	100	1.05
Flying Squad. Man (Comb pipefitter, boilermaker, rigger, welder) (Daywork)	23	20	27	14	10	94	94	.99
Shop Machinist, All-Around (Daywork)	21	29	24	15	5	94	94	.99
Pipefitter, 1st Class, Outside Plant (Daywork)	17	22	27	15	10	91	91	.96
Operator, Pipe Stills, Stabilization Plant (Shift work)	22	19	16	19	15	91	91	.96
Operator, Sodium Plumbite Plant (Shift work)	17	16	20	16	17	86	85	.89
Automobile Painter—Finisher, Striper & Spray (Night work)	16	24	25	12	9	86	85	.89
Asst. Engineer, Electrical Power House (Shift work)	14	19	19	17	9	78	79	.83
Tool Checker & Tester (Daywork)	28	11	19	15	6	79	79	.83
Ship Loader, Wharves (Shift work)	4	8	33	10	16	71	70	.74
Tester, Viscosity (Daywork)	18	20	15	11	6	70	70	.74
Boilermaker's Helper, Outside Plant (Daywork)	6	7	33	5	10	61	61	64
Sample Room Attendant, Research Dept (Daywork)	14	10	23	9	6	62	61	64
Common (Heavy) Labor, Outside Plant (Daywork)	3	3	37	3	9	55	55	58
Induced Draft Engine Tender, Boiler House (Daywork)	6	8	23	12	7	56	55	.58
Janitor, Pipe Still Battery & Pump House (Daywork)	4	3	30	4	9	50	49*	.52
Stencil-Cutter & Shipping-Tank Gauger (Daywork)	8	6	19	8	6	47	49*	.52

*Jobs totaling 50 points and under placed in minimum-rate class

Fig. 5. Detailed Rating and Grading of Plant Hourly-Rated Positions

the committee much time. He or they should be attached to the personnel staff.

CHARACTERISTICS ROUGHLY CONSIDERED.—Any attempt to evaluate jobs without some analysis is guesswork. Hence it is necessary to determine divisional factors or characteristics of the work which taken together will account for successful operation. Perhaps the simplest set of characteristics which will serve this need is as follows:

1. **Previous training required.** This factor consists in determining the minimum requisite schooling and working experience to fit an individual for work in a particular occupation.
2. **Inherent demands of an occupation,** peculiar to the industry or factory under consideration. This division determines the skill required, accuracy demanded, as well as ingenuity and integrity required.
3. **Physical conditions** under which the work of an occupation is performed. This division determines the health and accident hazards, disagreeable conditions, physical effort, etc.

The **mental approach** of those engaged in this program must be purely objective and the leader or rate analyst must be constantly on guard to keep all committeemen free from subjective tendencies. "The determination of the relative importance of these characteristics involves a broad visualization of the conditions applicable to the organization under consideration and the greatest care must be exercised not to allow a narrow consideration of individual cases or minor variations to influence the minds of those engaged in the evaluation." (Findlay, N. A. C. A. Bul., vol. 19.)

To illustrate, assume that the relative importance in these major characteristics is as follows:

1. Previous training 50%
2. Inherent demands 40%
3. Physical conditions 10%

The above figures might represent the opinion of the evaluating committee in case of a high-grade machine shop or instrument factory, whereas if this work were being done for a steel mill, much greater importance would be attached to the third division of physical conditions and less to each of the other two. **Evaluation of occupations** in terms of the above three main divisions has been done as an aid to ranking with some success, but better evaluation can be accomplished by using more characteristics, and assigning them point weightings. Usually that kind of analysis is limited or lacking where the ranking method is adopted.

With the element of responsibility in mind, Burk suggests that, if the characteristics must be reduced to three, they be stated as follows:

1. Job requirements. This would include the capacities and abilities which the individual must bring to the job, and the degree to which the job calls on the use of these.
2. Responsibility or importance. This would include the "load" which the company puts upon the individual with the required capacities and abilities, and can be measured or weighted from the point of view of the probability of error and improvement and the possible consequences thereof.
3. Working conditions. This would include factors such as health and accident hazards, disagreeable conditions, physical effort, etc.

PROCEDURE FOR RATING.—Jobs may already be classified broadly into four groups: manual, clerical, technical, and commercial. These are subdivided as to which sex is desirable, and the like. The Westinghouse Electric and Manufacturing Company classifies all its jobs into seven groups as follows (compare this with Fig. 2):

Group	Group
1. Policy	5. Interpretive
2. Administrative	6. Skilled
3. Executive	7. Unskilled
4. Creative	

With this as a framework the few characteristics which seem most suitable can be set up. If possible, a measuring scale should be contrived for each characteristic. Otherwise, poor guessing may defeat the whole objective. Next it is necessary to find the key-jobs, or at least the end-jobs, for each departmental group of jobs. Now all the jobs in each departmental group must be compared according to degree of some characteristic which it is believed the job requires relative to the key- or end-job requirements. On this basis the jobs are **ranked in series and recorded.** This step is now repeated for each of the other characteristics. The final series must be a composite since a job which ranks high in one characteristic may rank low in others. Hence the independent judgment of several judges, usually departmental committeemen, is important, and each rating should be recorded privately and more than once.

When agreement is reached as to a ranking list it is then desirable to close the jobs into classes (one company reduced 400 jobs to 23 classes, another reduced 500 jobs to 15 classes) and an approximately equal interval should be maintained between adjacent classes, say two- to five-cent rate intervals. This does not mean that the old rates should be allowed to influence the judges, except those for key- or end-jobs which were satisfactorily rated at the beginning, or staked at this time as a policy.

Job titles may now be remade to get a truer significance as:

Class 1. Diemaker #1, Patternmaker #1, Toolmaker #1.
Class 16. Lathe Operator #4, Milling Machine Operator #6.
Class 19. Assembler #5, Laborer #1, Janitor.

When the above procedure has been carried out for all departments a general committee, led by the same analyst, must harmonize the various lists.

THE SCATTER DIAGRAM OF RATED JOBS.—The next step should be to select a representative group of ten to fifteen standard hourly-rate key-jobs, rates of which range at intervals from near lowest to near highest rate, which have been in existence long enough to be well standardized, concerning which there has been no question as to adequacy of the rates, and which have been generally used in past rate setting as bases for comparisons with outside rates. One company found 40 such jobs. If possible, they should contain a fair percentage of jobs which are common at least to the whole industry in a particular locality and held by a reasonable number of employees. A so-called market survey of the rates paid for these jobs should be made periodically (Cook, A. M. A. Pers. Ser. 30).

Starting with these standard key-jobs, it is now possible to plot on a rectangular chart the class rankings of the jobs against the existing wage

rates and thus obtain a line or curve showing the general trend of the wage scale, as shown in Fig. 6. Class rankings are put on, as abscissas, along the horizontal dimension of the chart, at equal or assumed intervals, or better still according to point ratings. For each job rating on the horizontal scale, the corresponding wage rate existing or desired, in cents per hour or dollars per week, is plotted, as an ordinate, vertically above its job rating point. The series of points thus obtained, if connected or traversed by an inclined straight line, or a curve if the points conform more closely to such a shape, thus forms a typical or fixed wage-rate line or curve. For a job whose rating point has been set on the horizontal scale, the corresponding wage rate conforming to the general trend of wage scales set for the plant can be found by reading upward to the wage curve and noting what wage rate on the vertical scale corresponds to this point.

The wage curve may be practically a straight line if the range of classes is narrow, but this is not necessarily the case and any assumption that the line should be straight is wrong (Walters, Mech. Eng., vol. 60). A curve turning upward is the usual shape which results. The important thing is to check the line on several key-jobs as to their going rates in the community.

When an acceptable curve is found, then the "out-of-line" classes or jobs may be readjusted, that is, brought back to the curve. It is usually inadvisable to drop higher rates already in effect down to the curve because of the dissatisfaction engendered in workers whose rates are thus cut. New workers on these jobs, however, can be paid the correct rates. Prompt raising of the wage rate on any jobs below the curve, however, is good policy.

Inconsistencies are most likely to occur where jobs are highly specialized and consequently difficult of comparison. As these rates are minimums, a range of rates may be made for each class, but this procedure leads to overlapping and any such need may well be left for merit rating. This whole procedure will need to be repeated every five years or so.

JOB CHARACTERISTICS.—In any job evaluation program the **job only is being analyzed.** Man rating must come as a part of a separate program. Therefore, only characteristics which describe the job should be included in the study. Among the characteristics which have been found to correlate positively with wage rates are: "Scholastic content of the work; length of time typically needed by natively qualified but inexperienced operators to develop proficiency; physical resistance overcome by the operator during the work day; seriousness of possible errors on the job; originality of problems to be solved by the operator; degree to which the work is supervised; teamwork and personal contacts required of the operator; his supervision of others; hazards and disagreeable conditions which he must withstand at work; and any unavoidable expense caused by conditions of his employment." (Riegel, 7th Int. Mgt. Cong. Bul.)

Manual skill has been defined as "the ability to do work marked by precision, speed and quick accurate adjustment of motion paths to complex, intricate conditions." If this conception is stretched to include the knowledge and capability necessary to meet varying conditions together with capability of improvement, we find that skill so conceived is most important of the major characteristics in all jobs lying between

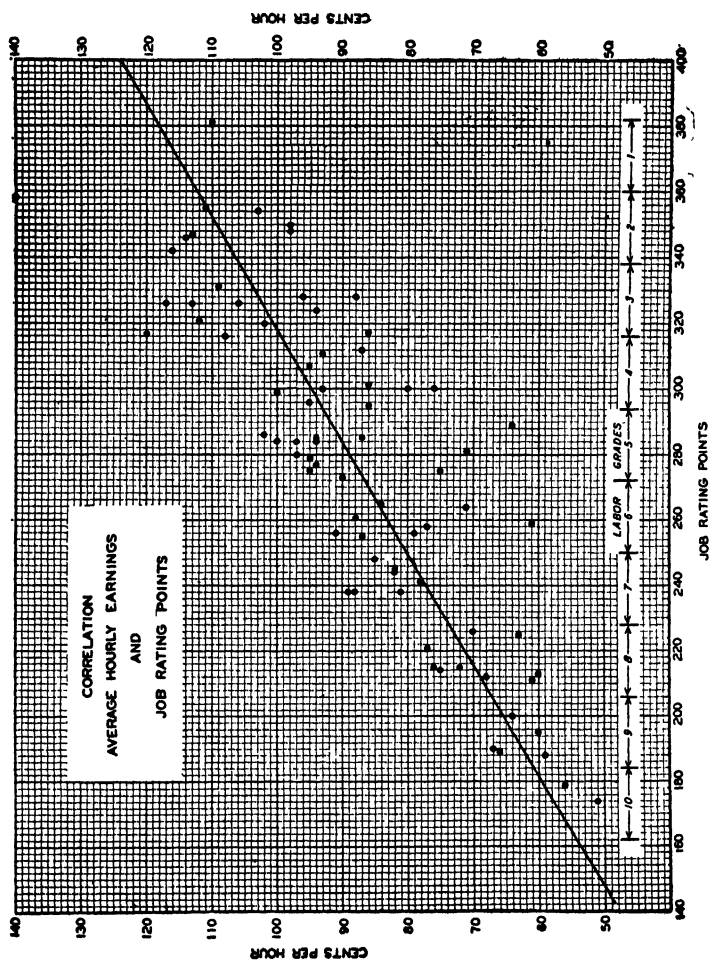



FIG. 6. Correlation of Average Hourly Earnings and Job Rating Points
(Natl. Metal Trades Assn.)

those classed as unskilled and those classed as supervision. This broad "skill" may be subdivided into mental and physical, into inherent and acquired, and others, but taking it broadly it permits simplification of the breakdown of characteristics. In short, the worth of all jobs can be measured in terms of four major job characteristics:

1. Skill that (with whatever composes it) which must be already possessed by the worker. What he must bring.
2. Effort, that which the worker must exert.
3. Responsibility, that which the worker must assume.
4. Working conditions, what the job does or can do to the worker, what he must hazard and endure.

All of these basic characteristics are present to some degree in every job, but do not carry equal importance and are not present to same degree in the various jobs. A survey by the National Industrial Conference Board (Bul. 25) indicates that the maximum weights given to these major characteristics by most industries fall within the following ranges:

Major Characteristic	Maximum Weights, in Per Cent
Skill	27.8–80.2
Effort	4.7–22.2
Responsibility	4.4–35.0
Working conditions	0.0–20.0

These **ranges of importance** are unduly influenced by the inclusion of records from a few exceptional companies. Eliminating extreme values from those above, the weights assigned by 60% of the companies fall within the following ranges:

Major Characteristic	Range of Importance, Per Cent	Median Importance, Per Cent
Skill	40.0–64.3	50
Effort	10.0–21.0	15
Responsibility	20.0–27.8	25
Working conditions	10.0–20.0	11

While this breakdown into four major characteristics has become almost universal, there is great discrepancy as to further procedure. For thorough analysis these four major job characteristics are too broad and must be subdivided to provide a safer method of evaluation. The Industrial Management Society plan has 23 while the National Electrical Manufacturers Association plan has 11.

A survey reported by Knowles and Means (N. A. C. A. Bul., vol. 20) showed many variations in the job characteristics used by companies in their job evaluation program. The following list summarizes these characteristics and shows the number of companies that use each characteristic in some degree. This report, however, makes no attempt to show how the various companies weight the characteristics which they use.

Job Characteristic	Number of Companies Using
Skill:	
Mental—Education required	13
Experience required	12
Physical	14

	General Foods Corp.	General Elect. (Wages)	General Elect. (Salary)	Revere Copper and Brass	U.S. Steel	Wright Aero.	Westing-house	American Optical	"A"	"B"	Cheney Bros.
SKILL											
Education	10		14.3		10	7.4	18.5		10	14	35
General		50						40			
Previous training	10				12	35.2	18.5			22	
Training time	10			16.6		13.3			20		
Details	10										
Resourcefulness	10					6.9					
Versatility	10										
Cooperation	10										
Mentality		12.5	7.1								
Analytical ability			14.3								
Initiative			14.3							14	
Personal requirements			14.3								
Manual dexterity				11.1	23						
Accuracy						19.5					
Aptitude							23.2				
Job skill									10		
Adjustability									10		
TOTAL	70	62.5	64.3	27.7	45	82.3	60.2	40	50	50	35

Effort											
Mental	10	6.25	3.3	11.1	10		7.4				
Physical		6.25	1.4	11.1	6	4.5	7.4			10	
Visual							7.4				
Fatigue					5					5	
Honesty of effort						1.7					
Monotony						.7					
Total	10	12.5	4.7	22.2	21	6.9	22.2	22	15	15	0
Responsibility for											
General	10	12.5	3.1					27	25		35
Cost of errors						4.4	4.6			5	
Quality and product	10			22.2			4.6			5	
Materials					9						
Equipment				5.5	5		4.6			5	
Safety of others					5		4.6			5	
Supervision			15.5	5.5	5					5	
Money			12.4								
Total	20	12.5	31.0	33.2	24	4.4	17.4	27	25	25	35
Working Conditions											
General		12.5		11.1				11	10	10	20
Health hazard				5.5	5	2.2				5	
Accident hazard						2.5					
Surroundings					4	.8					
Current expense					1						
Total	0	12.5	0	16.6	10	5.5		11	10	15	20

1. Westinghouse Electric and Manufacturing Company makes an allowance for unfavorable working conditions as a supplemental factor to the above characteristics.
2. General Electric Company allows 400 base points in addition to the above characteristics.
3. Wright Aeronautical Corporation includes a characteristic "difficulty of locating work elsewhere" which is not strictly a measure of job worth.

Fig. 7. Summary of Job Evaluation Characteristics

Effort:	
Mental	14
Physical	14
Fatigue	4
Responsibility	17
Working conditions	13

The following headings, which should have no bearing on the job rating program, were also found to be in use.

Characteristic	Number of Companies Using
Prevailing wage	4
Opportunity for advancement	3
Cost of living	2
Profit of company	2

An ideal number of characteristics to use would appear to be seven or eight. A survey (Riegel, Bur. of Ind. Rel., Univ. of Michigan) of several companies having a job analysis program, showed that eleven characteristics were in common use. The author subdivided them into four main groups as follows:

Job Characteristic	Number of Companies Using
Skill:	
Scholastic content	7
Learning period	13
Effort:	
Mental application	2
Physical resistance overcome by operator	10
Responsibility:	
Seriousness of errors	11
Originality of problems	4
Degree to which work is supervised	4
Teamwork and public contacts required	4
Supervision exercised by operator	6
Working conditions:	
Hazards and disagreeable conditions	13
Expense to operator	2

From this study it appears that the median company uses seven job characteristics.

The N. I. C. B. Bul. (vol. 25) reports a rather extensive survey of industries using job evaluation. Nearly all of the job characteristics used by these companies can be divided into the four main groups as shown in Fig. 7. Average practice is to use nine job characteristics.

From all studies, it seems to be consensus of opinion that all jobs can be measured in terms of four major job characteristics but that this number is usually not sufficient to measure easily and accurately the small difference between the various job classifications. Use of fifteen or twenty job characteristics gives this greater accuracy, but entails an extraordinary amount of work when there are hundreds of jobs to be analyzed. Since Benge, Knowles, and Riegel all suggest that the number of subcharacteristics used should not greatly exceed seven, it might be well to subdivide each of the original four job characteristics into two subcharacteristics, making eight in all. An analysis of various surveys

and reports suggests the following subdivisions which appear to be common to most jobs and might therefore be standardized.

STANDARDIZED JOB CHARACTERISTICS

Skill:
- Mental (Education, experience, training, etc.)
- Physical (Manual dexterity, etc.)

Effort:
- Mental
- Physical

Responsibility:
- For supervision
- For material things

Working Conditions:
- Hazardous
- Disagreeable

For salaried positions characteristics may be the same but "Responsibility" must be subdivided to separate the various kinds, as for:

a. Other employees
b. Materials
c. Equipment
d. Markets
e. Money
f. Methods
g. Records

It is not necessary to set up "Mental Effort" as a separate major characteristic, or to use as subdivisions such factors as personality, tact, honesty, and cooperation. A job requires, for example, that the person be either honest or not; there are no intermediate degrees. These factors may be credited under skill or effort, or measured and considered in giving weight to responsibility.

MEASURING SCALES FOR CHARACTERISTICS.—Job evaluation, to be wholly successful, must rest as far as possible on measurable data. Its purpose is to determine equitable base rates and these are all-important both to the employer and employee. Union advocacy of standard wage rates anticipated the problem but did not solve it. The job analyst can solve it but not without gaining the confidence of labor. Not only is **employee cooperation** necessary for determining the values, but union approval is often necessary for sustaining them. Correct evaluation is too technical for mere bargaining but results must give mutual satisfaction, and the development of each rate may have to be explained to the union representative. Already a few employers are consenting to the **union demand** for some degree of participation in this procedure. With these conditions in mind it is urgent that scales of measurement be found for as many characteristics as possible. Fig. 8 shows one of the earliest attempts to set up a scale for the subcharacteristics of skill. Not only are some of the characteristics difficult to measure, they are even difficult to define. They must, however, be both defined and practicable.

In this connection, Burk stresses the point that measuring scales are effective only when the scales used are objective. In a case like Fig. 8, for example, factors A, B, C, D, E, and G are objective. Factor F depends entirely upon the conception of the rater of the definitions or certain qualifying adjectives and adverbs and is thus not rightly part of a measuring scale. Burk's contention is that at some point human judgment has to enter into rating. He has no objection to measuring scales so long as they are not used by raters in the hope that they are accomplishing a wholly scientific result.

(Sample characteristics only)

Payroll Title________ Rater's Name________

	0	2	4	6	8	10
A. Education needed by person of average intelligence to do work.	Grammar School	2 years High School	High School Diploma	H. S. plus Business or Vocational School	College Degree	College Degree, plus technical training
B. Previous experience in same or related work.	None	1 year	2 years	3 years	4 years	Over 4 years
C. Time for person of average ability to be trained on the job.	None	1 week	1 month	3 months	6 months	Over 6 months
D. Precision and accuracy required (machine work).	Rough work		.01"	.005"	.001"	.0005"
E. Chance of damage to machines, materials, or products.	Under $50/yr.	About $50/yr.	About $500/yr.	About $1,000/yr.	About $2,500/yr.	Over $5,000/yr.
F. Extent to which unforeseen difficulties require initiative and ingenuity	Work is wholly routine	Routine work with occasional problems (weekly)		Routine work with daily problems		New problems met constantly
G. Versatility required (No. of operations involved, e.g., milling, drilling).	1	2	3	4	5	6 or more

FIG. 8. Scale for Appraising Occupations and Positions (specimen characteristics only)
(Clerical Salary Study Committee Report No. 1, Life Office Mgt. Assn.)

Two Approaches to Measurement.—There are two approaches to this measuring of characteristics. One approach is to compare jobs, a whole series eventually, as to the relative amount of a characteristic involved in each job. This comparison starts with the recognition of end-jobs, that is, with finding which job calls for the greatest amount of a characteristic and which job calls for the least amount of a characteristic. Other jobs, one at a time, are then compared as to the same characteristic and a percentage or a proportionate point value is then assigned the characteristic for each job. With one characteristic so measured for all jobs, the process is repeated for each remaining characteristic.

The other approach is to predetermine several degrees for each characteristic, that is, to break each characteristic into progressive degrees which can be defined and assigned a relative value in percentage or in weighted points. The number of degrees is usually five, except for such characteristics as experience and education which may need a degree for each year. The weighted points are usually specified within a maximum-minimum range. The characteristics for any job may then be measured against these predetermined degrees. Naturally this method requires much care in making degree definitions and in allocating the appropriate values to them.

The comparison technique is preferred by some since it is more direct, and thereby promises correct relativity. But it is likely to be cumbersome for a large company and the predetermined degree technique can be equally reliable if well set up and consistently applied. In fact, the trouble with the comparison method is that it is less likely to be so consistently applied.

The National Electrical Manufacturers Association has defined characteristics which are practicable in electrical trades, the National Metal Trades Association has done the same for machinist jobs (Job Rating, Natl. Metal Trades Assn.), and the National Foundryman's Association is beginning it. Unfortunately, there are many discrepancies between definitions of characteristics in one concern and those in another.

Major Characteristics Subdivided for Rating.—In the absence of a definite and scientific measuring scale, the degree of any characteristic required in a job must be judged on a purely relative basis. To aid this process a scale of 10 is arbitrarily set up with portions of it assigned to degree divisions such as:

Exceptional 10–7 or to 4	(depending on the relative worth of the subdivision)
Above average 7–4 or to 3	
Little or none 1–0	

Subdivisions of a major characteristic are used as headings of vertical columns and degree divisions used as headings of horizontal rows. On this background the job's degree of the characteristic may be rated as shown in Fig. 9, in which the subdivisions of skill are used by way of illustration (A. M. A. Pers. Ser. 34). **Correct relativity** is more easily secured if all, or a majority, of the jobs are evaluated on a single characteristic before going on to other characteristics. Since skill is most important of these, a complete evaluation of skill accounts for a large portion of the total points and the remaining portions will each have

	Dexterity	Precision	Versatility	Adaptation Period	Ingenuity
Exceptional......	9	8 6	5	4	10 4
Above average....	6 5 4	5 4	5 4	3	3 2
Average.........	3 2	3 2	3 2	2 1	1
Little or none....	1 0	1 0	1 0	0	0

FIG. 9. Relative Rating of Subcharacteristics in Skill

a minor influence. Thus a job which gets **exceptional rating** on all subdivisions of skill (Fig. 9) will have a total rating of 36 for that characteristic. Some analysts multiply all rating factors by ten to get more working room. As far as feasible the subdivisions should be further defined and illustrated to guide in their evaluation. If all this is repeated successively for each major characteristic, the treatment of various jobs will at least be consistent and objective, if not rigidly scientific.

Analytic Evaluation of the Job

THREE METHODS OF ANALYTICAL EVALUATION.—After characteristics have been decided upon, subdivided, and defined, the worth of each job in terms of these characteristics can be determined. There are three analytical methods of making this determination.

1. Straight-point method, or assigning equal weight ranges to each characteristic.
2. Weighted-point method, or assigning different point ranges to each characteristic.
3. Valuation of jobs directly in money method, not specifying any maximum weight.

STRAIGHT-POINT METHOD.—When evaluating a job by the straight-point method, an assumption is made that all the characteristics should have ranges of values between the same maximum and minimum points. Some use as many as 25 job characteristics each of which is valued by the analyst from a minimum of one to a maximum of four points, giving a total possible maximum score of 100 points. Characteristics used by the Davison-Paxton Co. of Atlanta in this program and its scale of rating are given in Fig. 10 (Taylor Soc. Bul., vol. 13). This example only illustrates the point system of job evaluation, and is not meant to be taken as an ideal list of job characteristics. The advantage offered by the straight-point system is that some analysis of the characteristics is required. This advantage, however, can also be claimed for

	KIND	NONE	SLIGHT	AVERAGE	MORE THAN ORD	EXCEPT
SKILL	MANUAL	●				
	NUMERICAL	●				
	VERBAL					●
INTELLIGENCE	KIND	NONE	ROU TINE	TRADE JUDG	SUP JUDG.	MGR. JUDG.
	TECHNICAL				●	
	PRACTICAL				●	
PERSONALITY	KIND	NONE	LITTLE	ORD	MORE THAN ORD.	EXCEPT
	APPLICATION RELIABILITY COMPANY INTEREST				●	
	TACT				●	
	FORCE				●	
	ABILITY TO TEACH OR SUPERVISE				●	
TRAINING	KIND	NONE	LIMITED	GOOD	MORE THAN ORD	EXCEPT
	TRADE TRAINING				●	
	GEN'L EDUCATION				●	
	EXPERIENCE				●	
REPLACEMENT COST	VALUE	NONE	$10-19	$20-29	$30-39	$40-
	MARKET PRICE					●
	PRICE PERSON REQUIRED					●
OPPORTUNITY FOR PROGRESS	POSSIBILITIES	NONE	LIMITED	FAIR	GOOD	EXCEPT.
	WITH COMPANY				●	
	ELSEWHERE				●	
	TRANSFER POSSIBILITIES				●	
COMPANY TRAINING COST	COST	NONE	SMALL	ORD	MORE THAN ORD.	CONSID-ERABLE
	LENGTH OF TIME				●	
	TRAINING LOSS	●				
	POINT VALUE OF RATING	0	1	2	3	4

FIG. 10. Specimen of Clerical Job Rating

(Department—General Correspondence; Position—Section Chief, Adjustment Section; Job Rating Score—51 points.)

the other two methods of evaluating the job. Disadvantages more than outweigh the advantages, and are:

1. Too much dependence is placed on arbitrary judgment of individuals.
2. It assumes that a considerable number of specific characteristics enter into the hourly rate for every job.
3. Stress is placed on comparison of disparate characteristics constituting a job, rather than upon comparison of similar characteristics found in many or all jobs.

WEIGHTED-POINT METHOD.—Weighted-point system of evaluating the job attempts to overcome, or to minimize, disadvantages of the straight-point system. Lott, who pioneered in the weighted-point plan (Wage Scales and Job Evaluation), proposed the following steps to put the plan into operation:

1. There are fifteen characteristics which influence the worth of the job.
2. One hundred points should be distributed over the fifteen characteristics to indicate their relative weights in the particular type of job to be studied.
3. Rates or points from zero to ten should be assigned to each characteristic for each job to indicate to what extent that characteristic enters into the various jobs under study.
4. Score points should be determined for each characteristic of each job by multiplying characteristic values by assigned points. (Item 2 by item 3 above.)
5. Total job scores should be determined by adding individual score points of each characteristic.
6. Select a skilled and an unskilled job which are generally standardized in the industry and on a chart plot their pay against the points assigned above and plot a wage-rate point diagram.

The rates mentioned in step 3 can be set up on a scale basis to facilitate assignment of weights. For example, Lott suggested that for the characteristic "Time required to learn a trade" the following be used as a guide:

Years of Experience	Points Assigned
10 or more	10
9–10	9
8– 9	8
7– 8	7
6– 7	6
5– 6	5
4– 5	4
3– 4	3
2– 3	2
1– 2	1

After these tables are made for each of the fifteen job characteristics, the work of assigning rates for each job is much simplified and less subject to the arbitrary judgment of the job analyst. Lott's **choice of characteristics** is:

1. Time usually required to become highly skilled in an occupation.
2. Time usually required for a skilled person in the occupation to become adapted to the employer's needs.
3. Number of men employed in an occupation in the locality—the labor supply.

4. Possibility of an employee locating with another company with a similar earning capacity.
5. Educational requirements of an occupation.
6. Prevailing rate of pay in locality.
7. Degree of skill, manual dexterity, accuracy required.
8. Necessity of constantly facing new problems, variety of work.
9. Money value of parts worked on—possible loss to company through personal errors—unintentional.
10. Dependence that must be placed upon the integrity and honesty of effort of the employee.
11. Cleanliness of working conditions.
12. Exposure to health hazards.
13. Exposure to accident hazards.
14. Physical effort required.
15. Monotony of work.

These characteristics, except 3, 4, and 6, can be grouped under the four major headings for purposes of comparison with other plans, as follows:

1. Skill—items 1, 2, 5, and 7.
2. Effort—items 8, 14, and 15.
3. Responsibility—items 9 and 10.
4. Working conditions—items 11, 12, and 13.

The best practice today conforms to the four major characteristics and retains them as headings even where further subdivisions are used. This lends orderliness to the procedure and allows comparison with work of other companies. Although it may be too early to standardize with varying subdivisions, it is doubtful if the four major headings will need addition or subtraction. Hence they may be considered as standard.

Another practice which has much merit but is not so universal in practice is the **assignment of a fixed number of points for the job of least worth,** the one given the fundamental base rate. On a maximum evaluation of 1,000 points for the highest theoretical job this bottom job is given 400 points, and all other jobs are given the same 400 points as a foundation (Weed, A. M. A. Prod. Ser. 111). At the time these

Title of Key Job	Mental Requirement	Responsibility	Skill	Mental Application	Physical Application	Working Conditions	Above Fundamental Base	Total for Base
Diemaker 1	100	60	360	40	20	0	580	980
Patternmaker (wood)	100	60	340	40	20	5	565	965
Craneman (200 ton, 2 hooks)	35	70	120	30	10	0	265	665
Sand blaster	10	15	60	10	50	100	245	645
Air chipper	10	15	80	10	50	30	195	595
Sweeper	0	0	0	5	35	0	40	440
Fundamental	0	0	0	0	0	0	0	400

FIG. 11. Key-Job Base Points and Fundamental Base Points for Seven Key-Jobs

weightings were adopted most wage rates ranged between $.40 and $1.00 per hour and ten points made a convenient amount to use per $.01. This procedure recognizes that at least 40% of all requirements are a physically normal body, plus sanity, and perhaps ability to converse satisfactorily in an acceptable language. Thus, in Fig. 11, seven key-jobs are rated against that "dead load."

Examples of Weighted-Point Method.—The Wright Aeronautical Corporation uses the weighted-point system of job evaluation. The program was installed throughout the entire plant by a committee of sixteen supervisors acting as a group in reaching all decisions. Thirteen job characteristics were selected as describing all of the jobs and were weighted as follows:

	Characteristic	Weight in Per Cent
1.	Time required to learn trade	35.2
2.	Time required to adapt skill to work	13.3
3.	Difficulty in locating work elsewhere	.9
4.	Educational requirements	7.4
5.	Degree of skill and accuracy	19 5
6.	Ingenuity	6.9
7.	Cost of probable errors	4.4
8.	Honesty of effort	1.7
9.	Dirtiness of working conditions	.8
10.	Exposure to health hazard	2.2
11.	Exposure to accident hazard	2.5
12.	Physical effort	4.5
13.	Monotony of work	.7
	Total	100.0

After determining the above weights the committee assigned **rates from** 0 to 10 points to each job for each characteristic. This was done by first determining the job which, in the combined opinion of the committee, should have the maximum value of 10 points, and then rating all other jobs by comparison with it. To facilitate this rating, charts similar to those previously described were used. In fact, the characteristic "Time required to learn trade" was weighted by allowing one point for each year required, as Lott suggested. Total points for each job were then found by multiplying each characteristic weight by the rate assigned to that particular job. Evaluation for a patternmaker follows:

	Characteristic	Rate	×	Weight	=	Total Points
1.	Time required to learn trade	10.0		35.2		352.00
2.	Time required to adapt skill to work	3.5		13.3		46.55
3.	Difficulty in locating work elsewhere	.0		.9		0.00
4.	Educational requirements	10.0		7.4		74.00
5.	Degree of skill and accuracy	8.5		19.5		165.75
6.	Ingenuity	10.0		6.9		69.00
7.	Cost of probable errors	1.0		4.4		4.40
8.	Honesty of effort	6.0		1.7		10.20
9.	Dirtiness of working conditions	2.0		.8		1.60
10.	Exposure to health hazard	1.0		2.2		2.20
11.	Exposure to accident hazard	8.4		2.5		21.00
12.	Physical effort	1.0		4.5		4.50
13.	Monotony of work	0.0		.7		0.00
	Total					751.20

Jobs of toolmaker and janitor were selected for the high and the low points of the wage rate on a point curve. A straight line was drawn between these two points and this curve was used to calculate all of the other hourly rates. A safer method is that of the United States Steel Corporation subsidiaries which plots the relative locations of 36 key-jobs, derives a smooth curve to fit, and then interpolates. A widely used plan is that of the National Electrical Manufacturers Association, developed under the leadership of A. L. Kress (Natl. Elec. Mfrs. Assn., Ind. Rel. Bul. 43). The choice of characteristics and allotted points are given in Fig. 12, together with a typical job rating sheet, Fig. 13.

SKILL—Total Maximum Points		250
1. Education—maximum points	70	
2. Experience—maximum points	110	
3. Initiative and ingenuity—maximum points	70	
EFFORT—Total Maximum Points		75
4. Physical demand—maximum points	50	
5. Mental or visual demand—maximum points	25	
RESPONSIBILITY—Total Maximum Points		100
6. Equipment or process—maximum points	25	
7. Material or product—maximum points	25	
8. Safety of others—maximum points	25	
9. Work of others—maximum points	25	
JOB CONDITIONS—Total Maximum Points		75
10. Working conditions—maximum points	50	
11. Unavoidable hazards—maximum points	25	

FIG. 12. Job Rating Characteristics and Weights

DIRECT-TO-MONEY METHODS.—While the weighted-point plan overcomes most of the disadvantages of the straight-point plan, it still has one possible disadvantage. This is difficulty of assigning maximum weights to the job characteristics. The plan makes no provision for extremes in job characteristics, such as health and accident hazard, and poor working conditions of such jobs as caisson work. To meet this situation the following **points for developing a job evaluation program** have been suggested (Benge, Ind. Rel., vol. 3):

1. The evaluation scale should be expressed in cents per hour, not in points.
2. The number of characteristics on which job judgment should be based should not exceed seven.
3. Job specifications should be subdivided into the same categories as the evaluation scale.
4. There should be no upper limit to the amount allowable for a given factor, so providing a scale sufficiently flexible to take care of new jobs, and of the extreme importance of a single characteristic.
5. There should be some means of comparing each characteristic of a particular job against that characteristic in comparable jobs, rather than against a predetermined scale for that characteristic.
6. Repeated judgments of a group of competent persons, using the job specifications, and spread over a considerable period of time, should be pooled to yield the final figures.

JOB RATING SHEET

JOB NAME AUTOMATIC SCREW MACHINE OPERATOR DEPT. SCREW MACHINE JOB NO. ____

GENERAL JOB DESCRIPTION

Set up and operate automatic screw machines, such as #00, #0 and #2 Brown & Sharpe Single Spindle or 9/16" and 1" Acme Multi-Spindle.

JOB REQUIREMENTS

MAN WOMAN BOY SPEC. AGE REQ. 30–45 years

HRS OF WK (IF NOT REG.) Regular

REQUIRED EXPER. PREV. JOBS TIME 3 to 5 years on same or similar types of machines

APPRENTICESHIP Yes

DAY WORK RATE		AVE HOURLY EARNINGS	OCCUPATIONAL WAGE
START	MAXIMUM		
.85		$1.05	$1.02

JOB ATTRIBUTES	OBSERVERS EVALUATION					
	1ST DEG	2ND DEG	3RD DEG	4TH DEG	5TH DEG	POINTS ASGND
SKILL						
EDUCATION			✓			42
EXPERIENCE				✓		88
INITIATIVE & INGEN				✓		56
EFFORT						
PHYSICAL DEMAND		✓				20
MENTAL OR VIS DEMAND				✓		20
RESPONSIBILITY						
EQUIPMENT OR PROCESS			✓			15
MATERIAL OR PRODUCT		✓				10
SAFETY OF OTHERS			✓			15
WORK OF OTHERS			✓			15
JOB CONDITIONS						
WORKING CONDITIONS				✓		40
UNAVOIDABLE HAZARDS			✓			15

TOTAL POINTS 336

LABOR GRADE 3

DETAILED DUTIES

1. Get necessary cams, chucks, tools, etc. from tool crib according to job layout.
2. Set up and adjust machine.
3. Grind and sharpen cutting tools and blades.
4. Operate group 2 to 5 machines depending on work requirements.
5. Determine proper feeds and speeds, where not specified.
6. Maintain tool set-up.

SPECIAL QUALIFICATIONS

1. Work from prints and job layouts.
2. Able to select proper cams, tools, chucks, cutters, blades, etc if not specified on layout.
3. Work to close tolerances using complicated tool set-ups.
4. Able select proper cutting lubricant.
5. May direct the work of helpers.
6. Education equivalent to grammar school plus 4 years apprenticeship.

SAFETY REGULATIONS AND HAZARDS

Remote possibility of dermatitis from cutting oils and lubricants.

FIG. 13. Job Rating Sheet

In this method, after job characteristics are selected, ten key-jobs whose rates are believed to be correct are picked, and the present wage rates of these jobs are distributed to the job characteristics by each analyst. Analysts are then asked to rank the jobs for each characteristic in order of the degree to which that characteristic is present. This serves to check and to show up any errors that were made in the original distribution of the wage rate to the various characteristics. These discrepancies can be discussed by the committee and corrections made in the distribution. Every other job can then be evaluated by **comparison to the ten key-jobs.** This is usually done by rating all jobs for one characteristic at a time and assigning a definite wage rate to each job for each characteristic. The total wage rate then will be the sum of the individual rates assigned.

Examples of Direct-to-Money Method.—The Atlantic Refining Company uses a modified form of the Benge system of job evaluation. The job-rating committee was made up of five job analysts and five operating representatives (Personnel, vol. 2). The following job characteristics were selected as being critical in that particular industry:

1. Skill.
2. Mental effort.
3. Physical effort.
4. Responsibility.
5. Working conditions.

The first concern of the rating committee was to select fifteen key-jobs. These jobs had to be common to the industry, they had to involve a **range of wage rates,** and they had to be jobs whose wage rates were not questioned. The names of the fifteen key-jobs were written on cards, and each member of the committee was asked to sort the cards privately into the order of importance for the characteristic "skill," basing his decisions on the job specifications which had been previously drawn up by the job analysts. This ranking was repeated for each of the other characteristics. After a three-week interval, without forewarning, committee members were asked to rank the jobs for the second time for the same characteristics. At end of another three weeks a third ranking by each committee member was asked for. These 30 rankings—three by each of the ten committee members—were averaged, and the averages discussed and adjusted in a committee meeting.

Members of the rating committee were then asked to **distribute the current wage rates of the key-jobs** over the five job characteristics. This distribution was also repeated twice at intervals. These distribution sheets were then checked against the rankings previously made. It was found that five of the key-jobs were out of line. These five jobs were excluded from the key list. The final result of this rating was **five measuring sticks** each of which had a wide range of values and was marked off in ten intervals against which every job in the plant could be compared. The five job analyst members of the rating committee ranked each job against each of the five measuring sticks mentioned above. Other members of the committee criticized and adjusted the rankings.

At the time of installation of the system, a general increase of 5% was made effective. The point ratings were corrected simply by multiplying each job rate by the factor 1.05. (See Figs. 14a, 14b, and 5.)

Payroll Title Operator   **Alternate Shift Titles** Houseman   **Dep't(s)** Pt. Breeze Ref.—Refining

Approval H. V. Hume

Division(s) Cracking   **Location(s)** Polymerization Unit

Description of Duties

Under immediate supervision of assistant shift foreman in charge of poly. plant operations; exercises immediate supervision as necessary over engineer and fireman and personally performs duties in control house and on operating platform for attaining and maintaining required temperatures, pressures, levels, and flows for the safe and efficient operation of the poly. plant in receiving and purifying refinery gases by removing the hydrogen sulphide; for preparing the gases for polymerization by removing those constituents which are too light or too heavy for polymerization by absorption and fractionation; for polymerizing the prepared charge by use of high temperature and high pressure and subsequent fractionation and condensation to separate the poly. gasoline produced and to recover those components fit for further polymerization.

Receives oral orders from assistant shift foreman concerning any special operating conditions, otherwise performs the work in accordance with routine and accepted methods. Continuously observes indicating and recording temperature, pressure, flow and level gages and instruments on panel in control house. Attains and maintains specified operating conditions by adjustment of remote-control mechanisms and valves in control house and on operating platform. Observes furnace temperatures and makes adjustment from control house when burning gas, or orders fireman to make required adjustments when burning fuel oil. Observes temperatures in towers, condensers, coolers and accumulators, and adjusts to required temperature by regulating flow of cooling water or propane refrigeration, by regulating steam to reboiler, and by regulating reflux rates. Observes rates of flow through all parts of the equipment and makes adjustment with remote-control instruments, or orders engineer to make adjustments at the pump. Hourly, fills in poly. plant operating log for both recovery and polymerization systems. Calls any unusual variations to attention of assistant shift foreman and assists him in bringing the operation back to normal. Checks operation of automatic pressure controls on absorber and poly. tail gas, and operates emergency pressure control on hydrogen sulphide to acid plant. Regulates water on coolers cooling gas for the purification system. Regulates steam on heaters heating gas to expanders. In emergency, operates emergency stops for all pumps at poly. unit from wall outside control house. In emergency and on order of assistant shift foreman, operates emergency control for dropping furnaces out and putting steam on furnaces.

Specification Number	Payroll Title	Total Points / Base Class	Rates
350	Operator	Total Points 101 Base Class 100	Conv. 1.05 = $1.05

Fig. 14a. Hourly-Rated Job Specification (*face*)

PERSONAL QUALITIES Reliability 30% Observation 25% Practicality 15% Thoroughness 15% Industry 15%

MENTAL EFFORT 24	SKILL 23	PHYSICAL EFFORT 16	RESPONSIBILITY 22	WORKING CONDITIONS 16
FORMAL EDUCATION OR EQUIV H. S. 2 required KIND OF SPECIAL EDUCATION None KIND OF TECHNICAL KNOWLEDGE None HIGHEST MATHEMATICS USED Percentage X READ BLUEPRINTS ENGLISH Complete JOB INSTR. REC'D *Job*—oral—written—routine *Method*—self—oral—routine—written JOB INSTR. GIVEN *Job*—oral *Method*—oral C GRADE OF INTELLIGENCE REPORTS Find and enter	SKILL REQUIRED TO START ON JOB Thorough knowledge of the operation of this unit. Names and location of all parts of the unit. How to maintain and attain oper cond. by use of remote-control mechanisms and valves. How to start up and shut unit down. PREVIOUS TIME TO ACQUIRE AND WHERE 6 to 12 months as engineer at this location, plus 6 to 12 months in lower-grade job at this location ADDITIONAL LEARNING TIME REQ. ON THIS JOB 1 week FURTHER TIME REQ. FOR PRACTICE BEFORE NORMAL PROFICIENCY 1 month PRECISION LIMITS AND DECISIONS Decisions for adjusting flows, temperatures, pressures and levels within routine limits. May not deviate from routine except in emergency.	ACTIVITY Walking Standing OPERATION Varied CONTINUITY Intermittent REQUIRED REST PERIODS None STARTING AGE LIMITS 24—55 HEIGHT AND—OR WEIGHT Normal SEX AND COLOR M.R.—W.R. STRENGTH Normal EYESIGHT Normal HEARING Normal ABNORMAL FATIGUE None	FOR EQUIPMENT For oper control and entering data according to routine of special instructions in order to maintain safe and efficient operation. FOR TOOLS None FOR MATERIALS Raw: purified refy gases. Processed: poly. gasoline, absorption oil, gases. FOR SPECIAL SAFETY PRECAUTIONS Plant rules and spec. precautions FOR SUPERVISION EXERCISED Immediate supervision of engr, fireman as necessary FOR SUPERVISION RECEIVED Immediate supervision of asst. shift foreman	PLACE Indoors—90% Outdoors—10% SURROUNDINGS Desk—control panel and instruments, high press and high temp. poly equip Clean, orderly. ATMOSPHERE Normal and natural Some fumes and odors. TEMPERATURE Normal and natural. ILLUMINATION Natural and good artificial HAZARDS Strains to nerves plus usual hazards of high press. and high temp. stills. PROMOTIONS To assist shift foreman REGULARITY OF INCOME Steady HOURS Regular shift.

SPECIAL REMARKS:

FIG. 14b. Hourly-Rated Job Specification (*reverse*)

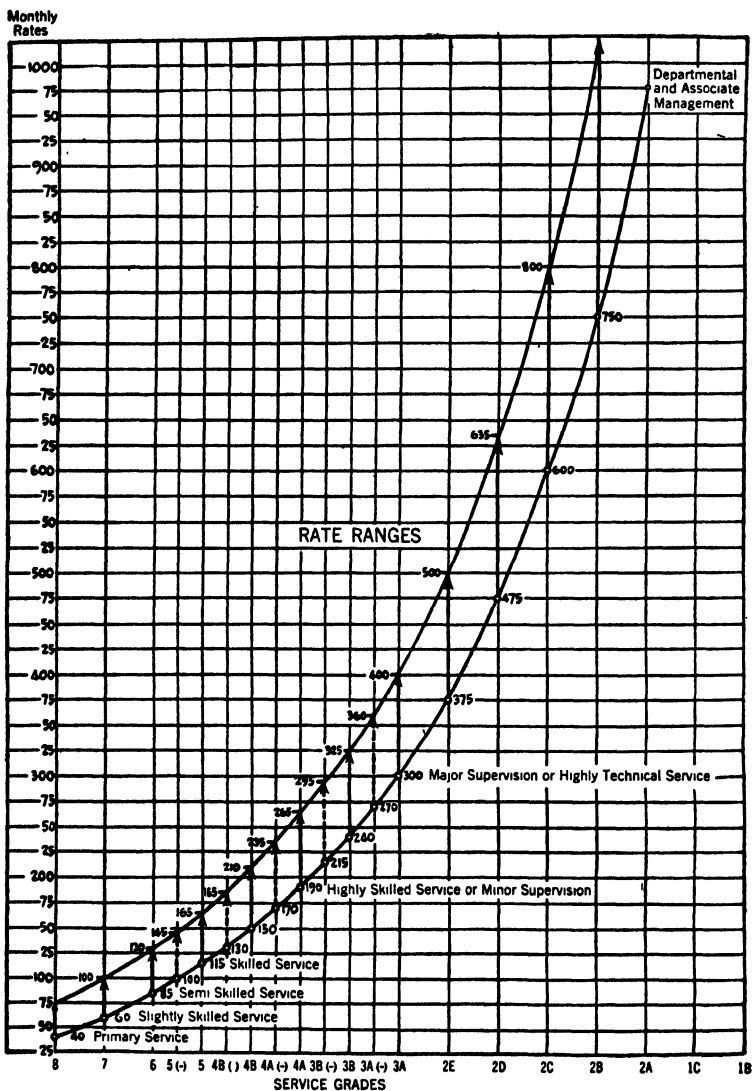



FIG. 15. Rate Gradation of Minimum and Maximum Rates by Service Grades

In case the points representing key-jobs do not fall on a straight line, this should not be interpreted as indicating that they are all wrong. It is possible that the straight line itself is wrong.

EXAMPLE OF EVALUATING A COMPLETE SERIES.—Since job evaluation aims to correct "out-of-line" rates it is important to find true line early in the procedure. Hopwood studied all jobs up to departmental and associate management (Hopwood, Salaries, Wages and Labor Relations, and A. M. A. Mgt. Ser. 55). With this more complete series he found that **trend line** was approximately **a parabola,** that is, the slope increased as it ascended (see Fig. 15). He began by classifying jobs into levels and functions, allowing a range of values for each level (see Fig. 16). Rates here shown are not actual but assumed for illustration. Note use of ranges. It is difficult to avoid their use

SERVICE GRADES		FUNCTIONAL CLASSES							RATE RANGES
		Accounting	Boiler Operating	Clerical Service	Designing	General Administration	Machine Construction	Selling	Monthly Basis
I MANAGEMENT 1 General Management	A					President			$2,500-4,500
	B					Vice President			1,700-2,800
	C					Gen'l Mgr			1,250-1,850
2 Departmental and Associate Management	A	Comptroller							$975-1,350
	B								750 1,025
	C	Gen'l Auditor							600 - 800
	D				Mechanical Engr			Sales Mgr	475 - 635
	E	Auditor				Executive Asst	Plant Supt		375 - 500
II OPERATING PRACTICE 3 Supv or Highly Tech Service	A	Sr Accountant			Chief Designer			Jobbing Salesman	$300 - 400
	B	Accountant			Senior Designer		Machinist Foreman		240 - 325
4. Highly Skilled or Minor Supervision	A	Jr Accountant	Boiler Engr	Chief Clerk	Designer		Machinist 1st Cl		$190 - 265
	B	Bookkeeper	Asst Boiler Engr	Senior Clerk	Asst Designer		Machinist 2nd Cl	Salesman in Sales Room	150 - 210
5. Skilled Service		Asst Bookkeeper	Boiler Operator	Clerk A	Junior Designer		Bench Hand		$115 - 165
6. Semi Skilled Service			Stoker Operator	Clerk B	Draftsman		Machinist Helper		$85 - 130
7 Slightly Skilled Service			Ashman	Asst Clerk	Tracer		Laborer		$60 - 100
8 Primary Service				Junior Clerk	Junior Tracer		Shop Boy		$40 - 75

Fig. 16. Coordination of Service Grades and Rate Ranges

(Titles, placements, and rate ranges are illustrative only.)

for the higher jobs. Mid-points are derived by evaluation, and the maximum and minimum limits are set above and below to provide for four or five rates with about 10% differentials. Twenty to 30% are more usual limits from the mid-points (Burk, A.M.A. Pers. Ser. 49). While it is possible to fix ranges which do not overlap, more latitude is provided if maximum of first grade extends to mid-point of second grade, and minimum third grade extends to mid-point of the second grade and so on. This procedure allows hiring at rates below the normal and provides an incentive within each grade without destroying the promotional program. The Industrial Management Society plan disregards specific grades altogether and allows a 20% range for every job. This plan is more confusing since the individual jobs are likely to come close together in rates. In any case changing employee rates should not come too easily, else there will be constant pressure to get the next rate and discontent for all who are below the top rates.

When salaried positions are included, as in the Hopwood example, monthly rates must be translated into hourly rates, or vice versa, for sake of a common ground. The advance classification of this plan can be extended through subdivisions as far as may be needed. For instance, grade A may include A_1 to A_8, etc. Thus letters can indicate functional nature, and numbers indicate levels of worth (see Fig. 2).

Rate Structures

RATE STRUCTURE FOR WAGE EARNERS.—After jobs have been either ranked or weighted in points, some determination must be made of the wage rates that are to be paid for the various levels of work from lowest to highest ratings. This determination must be checked by a survey of rates currently being paid in the locality on selected key-jobs. These key-jobs must be stable jobs about which there is little or no chance of controversy concerning wage rates or, to the same end, they must be jobs which can be easily identified and compared with similar jobs in other plants.

When the **evaluation process** has been completed, a practical rate structure must be devised. That is, the entire series of jobs must be divided into groups of labor grades or classifications, each grade having a fixed compensation or compensation range. The ranking method results directly in such a structure, with the disadvantage, however, that the number of classifications is limited, and the difference in compensation between adjacent grades is usually quite large. The weighted-point method, on the other hand, makes it possible theoretically to arrive at a compensation in cents per hour for each individual job. This exactitude is usually considered a little too refined and a rate structure is set up with a difference of at least $.02 per hour between successive grades, with each grade defined by the corresponding point range. The rate for each grade can be expressed in cents per hour or as a percentage of the rate for the lowest grade.

Use of a Compensation Range.—Many companies, instead of setting a fixed compensation rate for each labor grade, use a **compensation**

range so that minor wage adjustments may be made according to merit rating for any individual employee, without demotion or promotion. A total spread of from 20% to 30% is usually considered adequate for each grade. This method may have a serious disadvantage, however, in that employees are likely to press for the maximum rate of their grade. Moreover, if the plan is at all arbitrary, it provides opportunity for foremen and supervisors to show favoritism. Having a range for each grade usually means that grades are allowed to overlap. Thus one method of fixing the range for each grade is to say that the standard wage in one grade is maximum for the grade below and minimum for the grade above. The **rate paid unskilled beginners** is often the rate for several grades below.

Examples of Rate Structures.—A typical rate structure **without overlaps** is one used by Revere Copper and Brass, Inc. (N. I. C. B. Studies in Personnel Policy 25). It establishes definite rates, about 5% apart, from $.50 to $1.35, which follow approximately a straight-line wage curve. This scale is shown below:

$.02 Intervals	$.03 Intervals	$.04 Intervals	$.05 Intervals
$.50	$.60	$.78	$ .90
.52	.63	.82	.95
.54	.66	.86	1.00
.56	.69	.90	1.05
.58	.72		1.10
.60	.75		1.15
	.78		1.20
			1.25
			1.30
			1.35

The company's policy regarding **general wage adjustments** is that, when a general increase or decrease is to be made, all jobs will be shifted up or down the same number of steps. The standard is the base for incentive workers which makes it possible for them to earn above the evaluated rate. One step below the evaluated rate is assigned workers who are not fully qualified and two steps below is assigned beginners.

The Wright Aeronautical Corporation has 30 labor grades for its hourly rated employees with hourly rates increasing in alternating steps of $.03 per hour and $.02 per hour. A portion of the scale is shown below:

$.70	$.80
.73	.83
.75	.85
.78	.88

After $.88 there are increasing increments to $1.35.

RATE STRUCTURE FOR SALARIED EMPLOYEES.—The Pennsylvania Company, a commercial bank and trust company in Philadelphia, Pennsylvania, uses a modified Benge method system for about 1,200 salaried employees. Its overlapping rate structure is given below:

Salary Grade	Monthly Salary Minimum	Monthly Salary Maximum	Salary Grade	Monthly Salary Minimum	Monthly Salary Maximum
A	$ 50	$ 67	L	$136	$181
B	55	73	M	149	198
C	60	80	N	163	217
D	66	88	O	178	238
E	72	96	P	195	260
F	79	105	Q	214	285
G	86	115	R	234	312
H	94	126	S	256	341
I	103	138	T	280	374
J	113	151	U	307	409
K	124	165			

When an employee reaches the maximum salary for his job he knows that no further increases will be forthcoming until he is promoted to a job in a higher grade.

HANDLING TRANSFERS.—Where there is no compensation range for each grade, no particular problem arises when transferring workers from one grade to another, the worker merely being paid the standard compensation for the grade to which he is transferred. In the case of temporary transfers, such as to help another department catch up, the worker should be paid the rate for his regular job. A **good policy** where there is a range for each grade is to pay a worker being transferred upward the rate nearest his previous rate and, when being transferred downward, the evaluated rate for the new job.

MAINTENANCE OF RATE STRUCTURE.—The job evaluation study and development of the rate structure is not the end of the problem. The system set up must be maintained. **New jobs** will have to be evaluated. Periodic wage surveys will have to be made and maladjustments thus discovered and corrected. Some method of dealing with employee complaints on wages should be formally established. A committee on wages, to which all wage complaints are referred, should be maintained. This committee should have only advisory authority, however, final decisions being left to the production executives.

Occasionally, one kind of skill will come into great demand and workers in that field will be able to demand higher wages. Such a situation can be met by putting the occupation into an **irregular classification** and paying whatever rates are necessary to prevent the workers from going to other employers. Great care must be taken to be sure that conditions really justify the increase and that it is not merely a case of yielding to concerted but artificial pressure by one group. In regard to wage agreements with employee groups or unions, it must be remembered that any labor agreement becomes vulnerable as soon as it becomes decidedly disadvantageous to either labor or management. Despite this instability, evidence is accumulating that union agreements are contributing to mutual satisfaction. When leaders of each side are well informed and reasonable in intention, the hearings before an impartial chairman are democratic and constructive.

DIFFERENTIALS FOR INDIVIDUAL MERIT.—Since base rates set by modern job evaluation are necessary for minimum acceptability, it becomes essential to provide for the extra values which are

contributed by individual workers. Promotion is, of course, the most satisfactory solution but it is not always possible or always desired. There are many instances where individual workers must remain for years on the same jobs or within the same class of jobs. Most such individuals acquire through experience either **extra skill or judgment** which results in better products or greater output per hour. In other cases their production may not increase but they have additional value through dependability, loyalty, versatility, ability to assume responsibility, ability to instruct, etc. For any of these assets they expect, and should be conceded, additional pay. Under an incentive plan much of this increase may be attained automatically but, even so, it is common to figure incentive wages in terms of standard hours through which the hourly rate can vary according to individuals. In short, there are many reasons for adding to the base rates what are termed **individual differentials.** As in the case of base rates themselves, these extra rates must not be left to arbitrary dickering. Here "man-rating" finds its proper place. Each company should formulate policies to cover this need and adopt one of the many systems of merit rating so that the individual differentials will truly reflect worth. Seniority regardless of merit is essentially a problem in layoff and rehiring, but it may also be a consideration for promotion, in which case individual rate differentials will be involved. Union agreements have recently affected company policies considerably in this respect (N. I. C. B. Studies in Personnel Policy 5, and Research Memo. 3).

ADJUSTMENT OF OUT-OF-LINE RATES.—It is usual to bring up at once below-line payroll rates to within the range of the derived rates. On the other hand, it is not always feasible to reduce those payroll rates that have gotten out of line above. To avoid all downward adjustment it is possible (a) to promote overrated operatives to higher class job where their old rates will fall within the derived limits, (b) if promotion is not practical, maintain the status quo and exclude such operatives from participation in any general wage rise which may occur, (c) hire new operatives at the derived rates and ultimately transfer the overrated workers, training them, if necessary, for other jobs. An evaluation case recently reported showed that 2,000 operatives had received increases in rate, 1,200 received no change, and 3,800 received slightly lower rates. Payrolls were decreased 4% to 10%, or an average decrease of 4.6%.

Operation of a Job Evaluation Plan

NATURE OF THE PROBLEM.—It will be evident from the information presented that job evaluation is not only a difficult but also a technical subject, whose principles are still in the formative stage. As pointed out by Burk, while the approach may be scientific, the solution is systematic rather than scientific, because judgment always has to enter into the result. Recognizing the same conditions, Dale Purves, Vice President, John B. Stetson Company, emphasizes the point that the present stage of development is not definitive or final and that the person inexperienced in the field will be well advised to secure competent assistance in dealing with the questions that must be faced.

PROCEDURES MUST BE STANDARDIZED.—A superficial job evaluation is valueless if not actually dangerous. To keep it dependable and worthy of confidence it is essential that the procedures be standardized and **in writing.** A plant and departmental committee must be carefully organized, subcommittees planned to save time, etc. Characteristics suitable to the work must be decided upon and scales of points allocated. Definitions and measuring scales must be prepared for the characteristics. Selection of key- or anchor-jobs must be made to reach each class if possible, and the number of classes set up may depend on this step. **Forms for job description-specifications** must be designed. The order of all steps and techniques for taking them will need to be standardized. Finally, arrangements for making adjustments and for settling grievances must be set up. Unless all these provisions are developed in advance there are sure to be irregularities which will disqualify the results of the evaluation. Since all evaluations are relative to a few bases, detailed rules, and adherence to them, are more important for this procedure than for some other management activities (Benge, Job Evaluation and Merit Rating, Natl. Foremen's Inst.).

COST OF DOING JOB EVALUATION.—According to Roberts (Iron Age, vol. 144) a large steel company, which had evaluated 3,000 jobs involving 7,000 operatives, claimed that cost of installation amounted to .5% of the payroll. An oil refinery, where 7,000 employees out of 12,000 were covered by job evaluation, reports the same percentage cost for installation, and adds that continued maintenance costs .1% of the payroll. Costs of getting the facts, setting up definitions, etc., constitute the bulk of the expense. Thus the cost does not vary materially with the method of evaluation used. However, the cost is higher in percentage for a small company. Cost of maintenance increases as the application extends to higher salaried jobs. The refinery mentioned above found that $10,000 jobs seemed to be the economical limit for such extension. For 7,000 jobs it was found necessary to employ permanently about eight analysts. Another company reports six analysts to maintain the work for 4,000 employees, 1,000 different jobs being evaluated.

By way of caution, in installing a job evaluation plan there is need for thorough selling (Coley, A. M. A. Pers. Ser. 39). Most companies take pains to explain every step to employee representatives. In doing so, the jobs in question may be explained in detail, taking each characteristic by itself. Thus management should convince labor of the facts, or be convinced by labor if the "facts" are inaccurate.

USES OF JOB EVALUATION.—The following is a tabulation of the uses that should be made of a **job evaluation program** (Caldwell, Iron Age, vol. 144):

1. To determine qualities necessary for a job when hiring new employees.
2. To determine qualities necessary for a job when making promotions.
3. To determine if the system of advancement in the particular plant is from job of lowest order toward job of highest order.
4. To determine the qualities necessary when bringing back men who have been laid off.
5. To support explanations to employees as to why a particular man would not be suitable for a given opening. Many seniority clauses

give preference to length of service only after the requirements of the job in the way of experience, etc., are satisfied. The fact that the job rating has been made up by an independent agency as well as the fact that the entire plant was rated, and not specific data on the job in question obtained, will carry weight.

6. To determine if men now occupying various jobs have the qualifications required by the specifications.
7. To determine if all men are placed to best advantage in the respective jobs available.
8. To analyze hourly rates and to determine if they are in line with the rating given.
9. To compare wage rates with similar occupations at other local plants.
10. To point out where the greatest opportunities lie for development of automatic equipment and improvement of working conditions. Obviously a company would be in a much better position if all jobs could be reduced to the level of the lowest rating, thus making it possible to employ all unskilled labor, working under ideal conditions. This point should be explained more fully. Any plant where job ratings are very high, indicating a predominance of highly skilled labor, usually is a plant where there are very few automatic operations. High ratings indicate places where it is most likely that improvements in equipment can be justified.
11. To train new supervisors. Obviously, specifications outlining duties of each man are useful in starting a new foreman on the job.
12. To facilitate explanations to an employee of the fact that any improvement in working conditions theoretically should mean a reduction in his wage rate. For example, if a worker is located in an unheated building and he insists on heat, resulting in installation of heating equipment, this improvement in working conditions lowers his job rating. Theoretically, the rate for the job should be lowered accordingly.

It is not advocated that automatic machines be installed or that better working conditions be provided for the express purpose of lowering workers' rates. However, if the employee is shown that he is paid a higher rate because his working conditions are not the best, he will probably be better satisfied with his job.

STEPS IN INSTALLING THE PLAN.—To accomplish these results, Caldwell continues, it is necessary to give the following attention to the details of the survey after specifications are drawn and rating work is completed:

1. Check specifications to see if there is agreement with the rater's opinions.
2. Determine if all jobs are included.
3. Establish consecutive numbers to jobs for identification.
4. Check number of men occupying each job.
5. Keep accurate running records of number of jobs and number of men occupying each job.
6. Determine by personal judgment whether the various elements used in making ratings are correct and logical to use as a basis for wage rates.
7. Check wage rates and determine how they vary from the normal for each job.
8. Set up wage-rate bands for each job.
9. Consider wage adjustments to get existing rates more in line with the theoretical.

10. Consider the elimination of hourly rates altogether, establishing in their place a rate for each job.
11. Analyze each man to see if he has the requirements called for in the specifications for his particular job.
12. Consider a semi-rigid schedule of promotions from jobs of the lowest rating to those of higher ratings.
13. Consider if the individual employee involved should be shown how his particular job has been rated.
14. Get an over-all picture of the kinds of labor used in the plant in question.
15. As new jobs occur set up new specifications for them.
16. As conditions are changed or machinery installed, the specifications for the particular job should be changed as well as the ratings.
17. Check a merit rating system for each individual employee to determine how well he fits into the job specifications.
18. Improve equipment and working conditions so as to reduce all jobs as far down the grading as is possible. An explanation of just what is meant by this statement has already been made.

COMPANY POLICY REGARDING WAGES.—It is difficult to set up any standard policies for companies in general but A. L. Kress has ventured to do this in outline as follows (Natl. Elec. Mfrs. Assn., Ind. Rel. Bul. 19):

1. The general wage level should be at least equal to the prevailing wage level for similar work in the community.
2. The wage for each job or operation in the plant should be determined, relatively with other jobs, with due regard for skill, responsibility, experience, physical demands and hazards.
3. Individual or group effort should be rewarded wherever possible, through use of an incentive method of wage payment, where such a plan can be properly applied.
4. Fair standards of performance should be set which can be reasonably and consistently attained.
5. Full information should be given to any employee regarding the wage-payment policy or plan. Management should discuss with employees, whenever requested, the setting of standards, the fixing of occupational wages, the computation of earnings, or the standards themselves.
6. A reasonable normal work week should be adopted (with provisions to meet seasonal demand or emergencies, if necessary).
7. Employees should be compensated for waiting time due to reasons beyond their control, under piecework or bonus.
8. Complaints arising from the operation of wage-payment plan should be investigated promptly and adjusted in accordance with the facts.

SECTION 17

MERIT RATING

CONTENTS

SECTION 17

MERIT RATING

OBJECTIVES OF MERIT RATING.—Merit rating is a tool for measuring the performance of workers—a tool for appraising the relative qualities of their different personalities with respect to the jobs they fill. It attempts to minimize the amount of subjective judgment usually found where one person appraises another, and to substitute, if possible, objective measures to appraise individual differences which at present are almost universally handled subjectively. It is primarily useful in evaluating worker performance on the job, and it is in this field that its chief advantage is to be found.

Merit rating may be used for other purposes and in conjunction with various tests—vocational, intelligence, etc.—but these uses are as yet comparatively less important, and since they require different procedures they are better left to separate treatment.

Merit rating has become **a requisite of good employer-employee relations** in nearly all kinds and sizes of industrial organizations, because it provides an effective medium for avoiding arbitrary supervisory attitudes toward labor. For the large firm its use partially overcomes the lack of familiar contacts found in the smaller shops, which are so essential if men are to be properly appraised and employed to best advantage. It has a similar advantage in the medium-sized shop, depending upon the degree to which supervisors and employees can develop mutual understandings. In the small organization, however, its value is largely restricted to the category of useful knowledge—the small factory or industry has a natural advantage in close relationship between management and labor.

Advantages.—Emphasis on merit rating grows out of an attempt on the part of industrial managers to seek scientific means to achieve the following named advantages (Knowles, Advanced Management, vol. 6):

1. **Better Understanding of Work and Men.** The development and operation of rating programs has forced those responsible for jobs and men to study them both carefully. The outcome is a better understanding of both the jobs to be done and those attempting to do them.
2. **Increased Production.** Employees who are rated appear to accept the existence of a rating program in the spirit of competition. An added incentive for superior achievement is thereby derived. In addition, those whose productivity does not come up to standard are uncovered and replaced.
3. **Special Abilities Uncovered.** The appraisal and comparison of employees in terms of prescribed standards have brought to light men having special abilities. This has facilitated selections both for promotion and transfer.

4. **Prejudice and Bias Minimized.** Merit rating reduces guesswork and snap judgment. In the appraisal of employees, objective measures are substituted wherever possible, and those who rate are asked to deliberate in arriving at decisions.

5. **Fair and Equitable Pay Established.** Merit rating makes possible fair rates of pay because all employees are appraised in terms of the same specific factors, and completed ratings are reduced to numerical values. To this extent they are comparable when used for determining pay.

It is highly important to recognize definite **limitations of merit rating.** Regardless of the quality of any plan being used, the results achieved can never be better than the judgment, honesty, and fairness of the men operating it. Furthermore, no rating system can ever replace leadership—there is no adequate substitute for an ability to inspire men to do their best. Merit rating is merely a tool which when properly wielded provides composite opinions of employees based on uniform, scientific procedure rather than the snap judgments of individuals. It is a means, not an end in itself. Finally, it is not a mechanism for setting wage rates but rather a tool for testing their adequacy. Its greatest value in this connection (wage determination) is when it is used in conjunction with job evaluation. The latter determines the base rate to those who meet the requirements of a job, and merit rating may be used to arrive at the wage differential to which each is entitled on the basis of individual differences.

This distinction is sharpened by Stewart M. Lowry, Director of Industrial Relations, The Procter & Gamble Co., as follows:

1. Job evaluation is a measure of the **job.** It classifies the job relative to other jobs. It is impersonal and establishes upper and lower limits of job classifications both as to point values and rates of pay.
2. Merit rating is a measure of the **man.** It establishes his relative position within a classification. It reflects his personal performance on the job. It is a guide to the specific rate within a classification.

CLASSES OF EMPLOYEES RATED.—There is a growing tendency to rate both plant and office employees. Firms cooperating in a recent merit rating questionnaire survey reported these groups as being subject to rating systems (figures represent number of times mentioned in replies):

All Employees 4

Plant		Office	
Direct laborers	31	Office workers	15
Indirect laborers	26	Salesmen	8
Supervisors	16	Executives	8
Salaried clerks	1	Engineers	1
All hourly-paid help	2		

Basic Principles Applied to All Types of Rating

COMMON PROCEDURES AND TECHNIQUES.—There are basic principles of rating employees which apply to the organization and conduct of rating programs at any level of an organization. Whether employees are shopworkers, or supervisors and executives, development

and operation of a rating program to measure performance in filling a job requires techniques and procedures which are essentially the same for all. These procedures will be presented in detail and the exceptions discussed in connection with suggested rating plans.

DEVELOPING RATING PROGRAMS.—Rating programs are best developed on the individual firm basis. Existing plans seldom directly fit the needs of particular firms. The development of the program itself cannot fail to arouse in those doing the rating, as well as in those rated, more interest in making the plan work—not only do they understand better the scope of their own work, but also supervisors and top management alike become interested in the rating program and want it to be productive of desired results.

Lowry stresses a cautionary note—to lean on the side of simplicity and not allow overenthusiasm to start a company in a plan that will not survive because of its complexity.

A **committee** should be appointed to develop and operate the rating system. Its chief duties will include careful consideration of each of the following steps:

1. **Job Specification.** Establishment of requirements for supervisory jobs if these requirements are not already formulated. Where job and salary evaluation plans are in use, specifications will be readily available.

2. **Purpose.** Formulating the aims and uses of the supervisory rating program.

3. **The Rating Sheet.** Developing the **rating form,** selecting the **type of form** to be used; deciding upon the traits or characteristics to be measured in the light of job and position analyses; developing a procedure for **scoring**—assigning point values to rating; determining a proper system for weighting **individual traits** in relation to jobs; consideration of **application of objective measures.**

4. **The Rating Procedure.** Determination of:

   a. Who will do the rating.
   b. What instructions and training will be given those doing the rating.
   c. How often ratings will be done.
   d. Who will check completed ratings.

5. **Use of the Results.** Formulation of policies regarding availability of ratings for general use of top executives, and reaching a decision as to how they shall be used to assist supervisors and workers to improve their job competence.

6. **Training of Raters.** Establishing and conducting a training program for those who are to make ratings.

7. **Educational Program.** The organizing and conducting of an educational program among those rated regarding the foregoing.

Typical rating committees in industry are composed of representatives from personnel departments, administrative staff members (top executives), and supervisors (foremen) when shopworkers are to be rated. Occasional committees, composed differently, consist solely of representatives from one category, such as top executives; and still others comprise members from many different sources, including subordinates of persons being rated.

JOB SPECIFICATIONS.—Appraisal of a person's effectiveness in any job can be truly meaningful only when there has been careful definition of the scope of the job, its limitations, and the demands it imposes on anyone who is to fill it properly. A good rating form, therefore, is one which attempts to measure a person's performance in terms of what the proper fulfilment of his job demands. The selection of job requisites which apply in particular instances is best done by men familiar with the job under consideration—those working on the job, those who supervise the job, and top management. A careful job specification will assist particularly in accomplishment of the following:

1. Determining the purpose of the rating program.
2. Deciding the characteristics and traits to be measured.
3. Providing a fair basis for comparing the measured performance to that expected.

Because industries differ in the organization of operating personnel, no job at any level of an organization is typical. Consequently, it is impossible to present a job specification which would be useful for all industries. The following, however, is a somewhat inclusive list of the type of information which organizations must seek in order to compile proper specifications for jobs and positions.

FACTORS IN DEVELOPING JOB AND POSITION SPECIFICATIONS.—It is important to understand clearly the factors which govern the development of job specifications. These factors are:

1. Skill and experience—dexterity and accuracy; the degree of proficiency in manual and mental skills required; quickness, deftness, coordination of eye and muscles demanded.
2. Educational development and intelligence needed—education required to fill job or position expressed as equivalent to grammar school, high school, or college.
3. Responsibility—demands imposed by job or position regarding safety of others, direction of subordinates; care that must be exercised in use of tools, equipment, and machinery; degree to which accountable for process development and efficiency.
4. Mental effort needed—breadth and depth of thinking, requirements for alertness and concentration, need for evaluating or deciding, extent to which thought must be converted to action.
5. Physical effort needed—the muscular effort and strength required to fill job or position properly.
6. Personality factors required—appearance, carriage, voice, tact, ability to get along with others, cooperation demanded, character, common sense, intelligence, etc.
7. Leadership qualities needed—initiative and ingenuity, originality, patience in dealing with others, capacities for growth.
8. Teaching abilities required—requirements for training others and instructing subordinates; capacities for learning; demands job or position imposes in learning new methods, meeting new situations, grasping new ideas.

The following apply particularly to supervisory and executive positions:

9. Personal productivity—amount of work job requires to be done personally; diligence and care that must be exercised in fulfilment of duties.

10. Productivity required of unit (department, firm, etc.) for which responsible—amount of output of satisfactory quality required to meet production schedules, departmental standards, etc.
11. Personal efficiency demanded—care and accuracy needed to complete necessary records and reports; importance of promptness in completing own work as related to position.
12. Efficiency demanded of unit for which responsible—extent to which economy and prevention of waste time, material, and equipment must be achieved; need for orderliness of equipment, tools, etc.
13. Special requisites—age limitations, citizenship, special language abilities, etc.

PURPOSE OF THE RATING PROGRAM.—Usefulness of the results of any rating program is enhanced through **restricting its purposes to as few as possible**—preferably only one. Rating programs are used most commonly to aid in making decisions regarding these matters: salary determination, promotion, transfers, hiring, layoff, and discovery of individual weaknesses. Occasionally ratings are used as a guide in rehiring employees who have been temporarily discharged, but this is not a common use. They should be more generally employed for the purpose of bringing out the **more effective use of manpower**—in which field most industries are definitely backward.

Methods of Rating

THE RATING SHEET.—No two rating forms are exactly alike in appearance, but all forms attempt to measure the presence or absence in individuals of the characteristics which are essential to meet the requirements set forth in the job or position specifications. In the interest of a simple and clear rating form, however, the specification factors must be rephrased and regrouped, and terminology developed that will cause the rater to think of the factors in terms of the **capacity of an individual to meet them.** Not only is it desirable to obtain the essential information through use of as few traits as possible, but also to describe in simple language the traits to be measured. Unless great care is taken in both connections, there will be confusion in the minds of the raters which will correspondingly lessen the value of the completed ratings.

TYPES OF RATING FORMS.—Regardless of the characteristics to be measured and the intended purpose of a rating program, the rating form used will necessarily be modeled after one or a combination of these four general types of construction:

1. **Graphic Rating Scale.** The graphic rating scale is one of the more accurate methods of rating but it has not been adopted widely. It is recognized by its distinguishing feature, a line about five inches in length for each of the traits to be measured. At regular intervals beneath this line are short descriptive phrases signifying different degrees of the trait, for checking by the rater; and at one end of the line is printed one of the following: (a) the name of the trait, (b) the name and a short description of the trait, or (c) merely a short description with the name of the trait left out. The last plan has the advantage of forcing the

SERVICE

INSTRUCTIONS FOR USE. On this rating form there are eight qualities on which You do not have to be concerned with their relative weights, but are asked to rate on compares with all other State employees doing similar work. Rate him by making a the employee always in terms of the whole group with the average or typical employee employee on each of the qualities. Do not omit any. If the employee has made no qualities is concerned, rate him at the midpoint of that particular scale.

DO NOT ATTEMPT TO RATE AN EMPLOYEE UNLESS YOU HAVE ADEQUATE below 1 or above 4 on any quality, please write your specific reasons for this in the dismissal from the service or promotion to a higher grade may be dependent on your

1. QUALITY AND QUANTITY OF WORK ACCOMPLISHED—Consider amount of work accomplished and ability to maintain a high degree of accuracy.

2. INDUSTRY AND INITIATIVE—Does employee apply attention, energy and persistence to his work? Does he need constant prodding or does he go ahead with his work and follow it through to completion?

3. DEPENDABILITY AND INTEGRITY—Consider the dependability of the employee in the discharge of every duty. Does he carry his full share of responsibility? Can you depend on him to be punctual? Is he honest in his dealing with the administration and his fellow employees?

4. KNOWLEDGE OF JOB AND ABILITY TO LEARN—Consider extent of knowledge of his own job and related jobs, the ease with which he learns new methods in his own job, and details of jobs related to his.

5. COOPERATION—Consider his attitude in acting jointly with associates and superiors for the benefit of the unit. Does he fit easily into the group?

6. JUDGMENT—Does he impress you as a person whose judgment is dependable even under stress? Is he hasty, erratic, biased, swayed by his feelings?

7. ATTENDANCE—Consider regularity of attendance and the employee's attitude toward time lost from work. Does he consistently take time out for trivial reasons or is he absent only when absolutely necessary?

8. VALUE TO THE DIVISION—In the light of all the evidence regarding this person's characteristics (whether mentioned above or not) how do you rate his personal value to the division?

FIG. 1. Service

RATING SCALE

to rate each employee. Obviously, some qualities have more importance than others.
each quality as independently and exactly as possible. Ask yourself how this employee
check (√) at that point on each scale where, in your judgment, he stands. Think of
rated at the exact center of the scale. Please be sure to record your rating of the
impression on you whatever, either favorable or unfavorable, so far as one of these

KNOWLEDGE ON WHICH TO BASE YOUR RATING—If you rate an employee
space provided for comments on the other side of this page. This is important since
rating.

1	2	3	4	5
Unsatisfactory performance	Very slow, but fairly accurate	Completes regular work in reasonable time without undue error	Completes more than average amount of work with great accuracy	Completes large amount of work of highest quality
Lazy, needs much prodding	Rather indifferent, needs occasional prodding	Does ordinary assignments of own accord and fairly well	Industrious and energetic, completes suggested supplementary work	Does far more than is expected. Sets and completes additional tasks.
Indifferent, does as little as he can, needs constant watching	Sometimes unreliable. Avoids responsibility. Satisfied to "get by"	Works acceptably. Honest and willing. As a rule responsible but needs some direction	Very dependable and honest. No disciplinary supervision required	Highly dependable. Thoroughly honest. Consistently constructive force in his group
Does not understand own work and unable to learn	Has fair understanding of own job, but unable to adapt to new conditions	Thoroughly understands own job, but slow to adapt to new conditions	Understands own and related jobs and will be promotional material	Understands all jobs in division and is good promotional material
Cooperates grudgingly. Inclined to make trouble	Gives limited cooperation	Usually cooperates willingly	Cooperates willingly and fits easily into group	Cooperates cheerfully and consistently and inspires cooperation
Notably lacking in judgment	Shows some tendency to react impulsively	Acts judiciously in ordinary circumstances, may be hasty in emergencies	Habitually shows good judgment	Shows unusually sound judgment under all circumstances
Takes advantage of every opportunity to take time out	Frequently absent	Average attendance, absent only when there is a good reason	Rarely absent	Always on the job
Low	Below average	Average	Above average	Superior

Rating Sheet or Scale

ESTIMATE OF QUALITIES

Date______________________ Report On______________________

Dept.______________________

This rating should be made with great care and fairness, for the best interest of the Company and the employee, being careful to avoid over-ratings from mistaken motives of kindness and under-ratings from prejudice. Be prepared to justify your ratings should occasion require.

The facts disclosed are valuable to the employee as well as to the Company. The employee should be encouraged to show improvement in those qualities which are rated low.

In each group, the employee should be given an appropriate rating (either 1, 2, 3, 4 or 5) for each subdivision thereunder, after which an "X" should be marked in the column that indicates a fair general average for the group. Estimates should be based on a comparison with other men in a similar status.

Qualities to be Considered	1 Outstanding (Exceptional)	2 Good (Above Average)	3 Satisfactory (Average)	4 Fair (Below Average)	5 Poor (Unsatisfactory)
GROUP 1—Ability to do His Work:					
Quality of work (accuracy and neatness).............					
Quantity of work done (industry, promptness, volume).					
Ability to quickly understand and follow instructions...					
General Ability................................					
GROUP 2—Knowledge:					
Knowledge of his own work........................					
Knowledge of department operations................					
Knowledge (engineering).........................					
Knowledge (manufacturing).......................					

GROUP 3—Work Habits and Personal Characteristics:					
Punctuality					
Attendance					
Deportment (self control, courtesy)					
Alertness					
Interest in work and earnestness in doing it					
Dependability when working without supervision					
Habit of keeping busy and avoiding idleness					
Co-operativeness (willingness to assist others)					
Loyalty to Company's interests					
Orderliness (in working methods and care of equipment)					
GROUP 4—Special Qualities:					
Initiative					
Judgment					
Adaptability					
Trustworthiness					
Originality (inventive ability)					
GROUP 5—Supervisory Ability:					
Capacity for taking responsibility					
Ability to plan work					
Ability to execute work					
Ability to train others in proper working methods					
Ability to lead others and secure co-operation					
Knowledge of the Company's business					
GROUP 6—Best fitted for:					
Sales					
Manufacturing					
Development					
Engineering					
Summary Rating of all Qualities—General Value to Company					

Fig. 2. Rating Sheet or Estimate of Qualities

EMPLOYEE'S RATING CHART
AC SPARK PLUG DIVISION
GENERAL MOTORS CORPORATION

DATE ________ EMPLOYEE'S NAME ____________ ____________ ____________ CLOCK NO. ________
(FIRST) (MIDDLE) (LAST)

RATING FOR PERIOD FROM ____________ TO ____________ OCCUPATION RATED ON ____________

QUALITY RATED	DETAILS OF QUALITY	PUT CROSS IN SECTION WHICH MOST ACCURATELY DESCRIBES DETAIL IN THIS EMPLOYEE					DETAIL TOTAL	QUALITY TOTAL	REMARKS
		UNSATISFACTORY NEGATIVE QUALITIES		AVERAGE	SATISFACTORY POSITIVE QUALITIES				
QUALITY OF WORK	ACCURACY OF PRODUCTION	MANY ERRORS & SPOILED WORK 4	CARELESS 2	AVERAGE 6	CAREFUL 2	MOST ACCURATE 4			
	CARE OF WORKING SPACE	SLOVENLY 2	CARELESS 1	AVERAGE 3	KEEPS SPACE CLEAN 1	VERY CLEAN AND ORDERLY 2			
	HANDLING OF MATERIAL	ROUGH 2	CARELESS 1	AVERAGE 3	CAREFUL 1	VERY CAREFUL 2			
QUANTITY OF WORK	SPEED OF PRODUCTION	VERY SLOW 4	SLOW 2	AVERAGE 6	FAST 2	VERY FAST 4			
	USE OF WORKING TIME	VERY WASTEFUL 2	LOAF WITH OTHERS 1	AVERAGE 3	GOOD 1	VERY BUSY 2			
	USE OF MATERIALS	EXTREMELY WASTEFUL 2	CARELESS 1	AVERAGE 3	GOOD 1	VERY CAREFUL & CONSIDERATE 2			
ABILITY TO DO OTHER WORK	ABILITY TO LEARN	DULL 1½	LEARNS SLOWLY ½	AVERAGE 2½	LEARNS QUICKLY ½	BRILLIANT 1½			
	ACCEPTANCE OF RESPONSIBILITY	BUCK PASSER 1	EVADES IT ½	AVERAGE 1	LIKES IT ½	SEEKS IT AND HANDLES IT WELL 1			
	INITIATIVE	LIVES IN A RUT 1	SELDOM OFFERS SUGGESTIONS ½	AVERAGE 1	RESOURCEFULLY SUGGESTIVE ½	VERY ORIGINAL 1			
	ABILITY TO DIRECT THE WORK OF OTHERS	ANTAGONIZES 1	HINDERS ½	AVERAGE 1	HELPS ½	EXCELLENT LEADER 1			

		VERY POOR	POOR	AVERAGE	GOOD	EXCELLENT		
ATTENDANCE		4	2	6	2	4		
CO-OPERATION	ATTITUDE TOWARDS COMPANY	ACTIVELY ANTAGONISTIC	PASSIVELY ANTAGONISTIC	NEUTRAL	CO OPERATES PASSIVELY	CO-OPERATES ACTIVELY		
		2	1	3	1	2		
	ATTITUDE TOWARDS SUPERIORS	DISREGARDS WISHES	FOLLOWS ORDERS LIKE SOLDIER	NEUTRAL	FOLLOWS ORDERS CHEERFULLY	TRIES TO HELP MAKE GOOD		
		1	$\frac{1}{2}$	$1\frac{1}{2}$	$\frac{1}{2}$	1		
	ATTITUDE TOWARDS FELLOW WORKMEN	PUTS BLAME FOR ERRORS ON THEM	LOOKS DOWN ON THEM	NEUTRAL	HELPS THEM WHEN TOLD	EXTREMELY CONSIDERATE		
		1	$\frac{1}{2}$	$1\frac{1}{2}$	$\frac{1}{2}$	1		
SAFETY HABITS	ATTITUDE TOWARDS SAFETY PROGRAM	DESTRUCTIVELY CRITICAL	FOLLOWS RULES DISINTERESTEDLY	NEUTRAL	OFFERS A FEW SUGGESTIONS	EXTREMELY HELPFUL		
		3	$1\frac{1}{2}$	5	$1\frac{1}{2}$	3		
	OBSERVANCE OF SAFETY RULES	OPENLY DISREGARDS	BELIEVED DISREGARDS WHEN NOT WATCHED	AVERAGE	OBSERVES ALL MAJOR RULES	OBSERVES ALL AND HAS OWN		
		3	$1\frac{1}{2}$	5	$1\frac{1}{2}$	3		
	ACCIDENT RECORD	MAJOR INJURIES THRU CARELESSNESS	MANY MINOR INJURIES	AVERAGE	FEW MINOR INJURIES	NEVER GETS MINOR INJURIES		
		$1\frac{1}{2}$	$\frac{1}{2}$	$2\frac{1}{2}$	$\frac{1}{2}$	$1\frac{1}{2}$		
PERSONAL HABITS	MORAL CHARACTER	KNOWN VERY BAD	QUESTIONABLE	AVERAGE	GOOD	OUTSTANDING		
		2	1	3	1	2		
	PHYSICAL CONDITION	VERY POOR	MANY MINOR AILMENTS	AVERAGE	GOOD	VERY GOOD		
		1	$\frac{1}{2}$	$1\frac{1}{2}$	$\frac{1}{2}$	$1\frac{1}{2}$		
	GENERAL APPEARANCE	SLOVENLY AND DIRTY	CARELESS	AVERAGE	NEAT AND CLEAN ALWAYS	EXCEPTIONALLY PLEASING		
		1	$\frac{1}{2}$	$1\frac{1}{2}$	$\frac{1}{2}$	1		
								← TOTAL NUMERICAL GRADING

RATED BY—(FOREMAN) ______________________ ASSISTED BY—(TITLE) ______________________

CHECKED AND APPROVED BY—(SUPERINTENDENT) ______________________ NUMERICAL GRADING BY ______________________

FIG. 3. Employee's Rating Chart

rater to read the description, meanwhile preventing him from utilizing any preconceived conception of the trait on the basis of its name.

A space is customarily reserved on the reverse side of the sheet for comments, general remarks, or, in a few cases, specific reasons justifying the ratings. When the ratings are completed, they are returned to the personnel department to be scored by use of a master stencil (similar to that in Fig. 7 appearing later). This stencil gives a numerical rating to each trait and makes possible statistical corrections for the tendencies of the individual raters. A total rating may be obtained by adding the scores on the individual traits. Moreover, in devising the master stencil, various factors may be weighted properly, both without inconvenience to the rater and influence on his judgment. The rater, for example, tends to avoid exceptionally high or low ratings of heavily weighted traits.

Another way in which to avoid the rater's tendency to limit his scoring of the individual traits to the same general percentage all the way down, is to reverse the order in which the descriptive phrases beneath the lines appear for a few of the traits, so that some read from good to bad instead of from bad to good.

Many employers feel that the graphic rating scale is of a higher degree of accuracy than necessary and, therefore, are unwilling to devote the additional time its use requires. Furthermore, those who score it must have access to much confidential information and this factor is regarded by many as a potential danger. An example of this type of rating sheet is shown in Fig. 1.

2. **Rating by Letters.** Use of letters to rate individuals is probably an outgrowth of school marking techniques; it simply names and describes the traits to be measured and classifies the employee by letters (E, G, F, P) into arbitrary groups. While it is one of the more popular methods now in use, its only recommendation is simplicity.

Since one of the chief functions of merit rating is the minimizing of subjective judgment, there is little to commend a system which groups employees into classes of excellent, good, average, below average, and unsatisfactory. Varying conceptions of these terms make comparison of different ratings nearly worthless. In addition, the method possesses all the disadvantages of method 3, described below. An example of this method is shown in Fig. 2.

3. **Rating by Grouping.** Rating by grouping is the most popular of rating methods. It is an extension of "rating by letters." Employees are again divided into groups, but the groups, instead of being differentiated just by letters, or the equivalent, as E for excellent, are somewhat more carefully described. In the final analysis, success of this method depends upon the accuracy of these definitions. Fig. 3, used by the A-C Spark Plug Division of the General Motors Corporation, is an excellent example of this kind of rating procedure.

Because of the wide use of "rating by groupings," it is desirable to consider briefly its underlying theory. Those who support this method assert that by making any ratings one is attempting, in general, to measure certain traits which are "nonmeasurable," and the presence or absence of which in human beings is due to the interaction of heredity and environment, while the actual extent to which the traits have any

bearing on the job will depend, in addition, upon the amount and kind of supervision.

This fundamental statement is followed by advancing the hypothesis that the frequency of occurrence of certain intelligence levels will follow a bell-shaped curve, and since, in general, the traits which we attempt to measure are governed to a large extent by the same factors, it is to be assumed that the frequency with which degrees of these traits occur will be shown by the same curve **as it has been modified by social conditions.** For example, in the case of regularity of attendance one might find that early public school training has skewed the curve, but it is still a curve.

Fig. 4 shows an evaluation of people by the method of grouping. In effect, this procedure established an arbitrary system of zoning, the

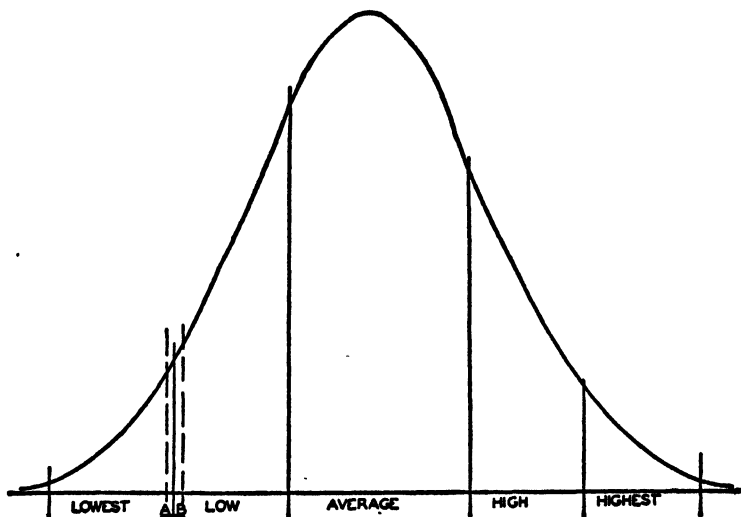



Fig. 4. Zoning of Traits in Merit Rating

result of which is to differentiate widely on the curve itself, between the two individuals whose respective abilities, for example, would place them on lines A and B, when in reality the difference is so slight as to be negligible.

The method, therefore, is not wholly fair to all who are being rated and introduces additional inaccuracies into a process which by nature can never be wholly accurate. Its advantages are ease of rating, greater accuracy than rating by letters, and simplicity of installation.

4. **Rating by Specific Items.** Newness of the specific-item rating technique has prevented its wide adoption and, therefore, it is subject to development. Rating is accomplished by use of a form listing several

items to be checked as either existing or not in the individuals under consideration. Its underlying theory is similar to that of the behaviorgram, defined by Bradshaw as "a narration of instances, supporting facts, or anecdotes illustrative of the behavior of the person being rated" (Strong, Psychological Aspects of Business), specific items being selected to serve as indicators of the presence or absence of more general traits.

The **specific-item method introduces speed into rating procedures,** but its success or failure depends upon the care with which the rating form is prepared and used. A thoughtfully developed form may serve as a reasonably accurate method even though the scoring is accomplished rapidly, while a carelessly prepared form, allowing full play of prejudice and bias, will be of little value. Those who contemplate using this method should devise the form and then test its reliability by comparing the results obtained with another rating blank of known reliability.

Fig. 5 shows a modified sample form.

Scoring

ASSIGNING POINT VALUES TO RATINGS.—To be most useful, completed ratings should be comparable (Knowles, Personnel, vol. 17). Comparability requires adoption of a common unit of measure, i.e., a scoring system. When dealing with human behavior, however, we have **no convenient physical units of measurement,** as in the physical sciences where various scales, conversion factors, and statistical measures are readily available. Ratings of individuals must be made as a matter of judgment rather than by means of an accurate scale. Numerical scales and weights function in employee rating as a device to facilitate more exact appraisal of personal traits by making possible comparisons of total scores computed for the individuals rated. One such form is shown in Fig. 5.

In reality, a rater is told to be precise when asked to evaluate an employee by a numerical scale (8 for Superior, etc.). But since selection and use of the scale involve individual judgment, the scale can supply only a common term for the expression of this judgment. **A primary requisite** in setting up such a scale is that the designation for each separate rank between imperfection and perfection must be in proper relationship to the whole scale. The particular arbitrary scale as selected is unimportant compared with a proper understanding of the scale by the raters and the interpretation of the final scores by executives.

WEIGHTING INDIVIDUAL TRAITS.—Particular traits are not always of equal importance in the performance of jobs and positions. This condition is particularly true in the case of supervisory and executive positions. Where traits have unequal significance in relation to proper filling of the jobs under consideration, it is necessary to construct weights which will give proper significance to each as related to the job or position—i.e., various factors should be recognized as **essential, desirable, or unimportant** in the performance of a job. A weighting scale must be devised to weight the significance of each trait in filling the particular position held to give a proper balance in each of the categories

(essential, etc.) as related to the job. For example, if no points were given a trait relatively unimportant to a particular job, but generally desirable in the character of all employees, this trait would be omitted from the rating. In fact, no irrelevant characteristic should be listed on a rating sheet.

Three possible scales for weighting the importance of traits with regard to jobs and positions follow:

	Scale No. 1	Scale No. 2	Scale No. 3
Relative importance of trait:			
Essential to fill the job	2	3	4
Desirable to fill the job	1	2	3
Unimportant to fill the job	0	1	2

Presumably, each of these scales supplies numerical units representing varying degrees of significance of traits with respect to jobs, from unimportant to essential. In any such scale it is advantageous to have the distance between each of its designated degrees in proper relation to the whole range. For example, the distance between desirable and essential on the first scale is one-half the whole scale, which makes too wide a gap. In turn, this tends either to penalize or value too highly certain traits, the possession of which as essential or desirable in filling a job may be questionable. The second scale somewhat lessens this gap and gives the same trait, considered as desirable, one-third less weight than it would receive were it weighted as essential to a supervisory job. The third scale appears to be fairest in weighting traits in relation to jobs because it narrows still further the gap between essential and desirable—to one-quarter the total scale.

The smaller the gap between the numerical weights in relation to the whole scale, the less will be the distortion of the total point ratings for various individuals. Application of these principles is made in the suggested supervisor rating form (Figs. 10a and 10b appearing later).

Traits may be weighted also in the assignment of individual point values to them. Different point values are applied to different traits to make ratings and to score the results. In establishing the maximum points to be allowed any trait, the rating committee recognizes the differences in **importance of traits** as related to the proper fulfilment of jobs. The final composite score of an individual who has been rated, therefore, reflects the weighting given to the various traits.

The Rating Procedure

WORK OF RATERS.—Among the typical firms having considerable experience in rating, the **actual rating** is done by those next in rank above the persons rated, or by top executives. Of 14 firms replying to a questionnaire which sought information on this point concerning supervisor ratings, only one stated that rating is done exclusively by the personnel department. Some organizations ask supervisors of the same rank to rate one another. Where this is done, great care must be taken to check the results for possible prejudice and bias.

EMPLOYEE RATING SHEET

Name .... Dept. .... No.............
Present Job .... Date....................
Rated By ....Foreman Total Service ....Yrs......Mos......Days
Checked By ....Supervisor From **Employment Record Card.**
Approved By ....Superintendent By ....Employment Dept.

I CUMULATIVE SERVICE

1 Yr	1	22 Yrs.....	11
2 Yrs.....	1	24 "	12
3 "	2	26 "	13
5 "	3	28 "	14
8 "	4	30 "	15
10 "	5	32 "	16
12 "	6	34 "	17
14 "	7	36 "	18
16 "	8	38 "	19
18 "	9	40 "	20
20 "	10	42 "	21

II DEPENDENTS

4 Persons 4
3 " 3
2 " 2
1 " 1

III MARITAL STATUS

Married Man 1
Single Woman 1

IV CITIZENSHIP

Citizen 5
Alien (Service 25 Yrs. or more) with or without 1st papers 5

Ans. Pts. (√)

VII QUALITY

A. To what degree is the product of the employee up to the department's accepted standard of quality?
1. Above standard requirements? Yes....1
2. Meets standard requirements? Yes....1
3. Not more than occasionally below standard requirements? Yes....1
4. Is this person employed on a job of high quality requirements? Yes....1

B. Workmanship
1. Is this person one who is orderly and handles tools and equipment properly? Yes....1
2. Does this person handle materials economically? Yes....1

C. Degree to which supervision check is necessary to maintain quality?
1. Needs little or no checking? Yes....1
2. Needs no more than average checking? Yes....1

FACTOR VII TOTAL CREDIT........

VIII VERSATILITY, ADAPTABILITY, SKILL

1. Has this person learned new work within the expected time? Yes....1
2. Is this person able to satisfactorily fill 2 major jobs without training? Yes....1
3. Is this person able to satisfactorily fill 3 major jobs without training? Yes....1

First Papers 3

Alien (Service 20 Yrs. to 25 Yrs.) 2

Alien (Service 15 Yrs. to 20 Yrs.) 1

V ATTENDANCE

Perfect 4
1–2 Absences 3
3–4 " 2
5–6 " 1
Over 6 " 0

VI QUANTITY

Day Workers

Above Average 6
Average 4
Below Average 2
Unsatisfactory 0

Bedaux Workers

80 Pt. Hr. & Over 6
70–79 Pt. Hr. 4
60–69 Pt. Hr. 2
Below 60 Pt. Hr. 0

4. Can this person readily adjust to radical changes in the requirements of his present job? Yes....1
5. Does this person show the capacity for learning different work? Yes....1
6. Would this person adjust readily to transfer to another major job? Yes....1
7. Can this person actually fill the job he is on with more than ordinary skill? Yes....1
8. Can this person perform a highly skilled job with apparent ease and dexterity? Yes....1

FACTOR VIII TOTAL CREDIT........

IX CONDUCT, COOPERATION

1. Is this person one who does not play pranks that might endanger other workers? Yes....1
2. Does this person refrain from objectionable language or actions on the job? Yes....1
3. Is this person always willing to carry out instructions and requirements of job? Yes....1
4. Is this person always willing to try new methods? Yes....1
5. Does this person use a helpful attitude in notifying supervision regarding conditions that require attention? Yes....1
6. Does this person call to attention of supervision defective work received? Yes....1
7. Is this person one who does not offer excuses or alibis to avoid accepting his proper responsibilities? Yes....1

FACTOR IX TOTAL CREDIT........

TOTAL RATING ....

REGULATIONS GOVERNING SERIOUS MISCONDUCT

Any serious violation of the rules of conduct involving intemperance, dishonesty, or other misconduct not covered by the above questions shall justify in addition to proper disciplinary action or discharge, a deduction of five points from the employee's current rating on Factor IX. Such action, however, shall be only after review and approval by the Manager of Industrial Relations.

REGULATIONS GOVERNING TARDINESS

Two points may be deducted from Factor V in the case of an employee who is habitually late.

FIG. 5. Employee Rating Chart with Points Value

Instructions.—It is most important that uniform instructions be given those who are to do the actual rating. Unless the same terminology and rules are applied by all who rate any individual, the results achieved will not be comparable and the persons rated may suffer from unfair treatment.

Frequency of Ratings.—While new employees occasionally are rated semi-annually, ordinary practice is to rate all employees once a year. Those cooperating in the special questionnaire study on rating practice indicated these special occasions:

1. Change of position.
2. When some occasion suggests desirability.
3. Prior to any change in supervision for supervisors.

Checking and Reviewing.—Most firms agree that it is good practice to have the completed ratings checked or reviewed by members of the personnel department or by some officers higher than the persons doing the rating. Moreover, it is generally thought that the new rating should be compared with previous ones. The comparisons usually are made by the personnel department, where data regarding individuals are on file. The principal value of reviewing is to reveal any great discrepancies in ratings and to ascertain whether or not the persons being rated are making progress. It appears to be the belief of most industries that **reference to previous ratings** prior to, or during, the rerating of individuals can arouse only prejudices and biases and may prevent giving credit for corrected faults.

USE OF THE RESULTS.—Completed ratings are most useful when they are analyzed to show how well individual employees meet the requirements of their jobs as defined in the specifications for their positions. With few exceptions, the firms whose plans have been studied discuss completed ratings with the persons rated. A primary purpose of rating programs is to uncover any individual shortcomings and to use completed ratings as a basis for making constructive suggestions. Ratings should never be concealed lest some of those rated come to doubt their real purpose. Secrecy regarding the results can breed only distrust and poor morale. The rating reports, however, should not be shown to anyone except the individual rated and those authorized to check the ratings.

TRAINING OF RATERS.—Rating programs produce the best results when both the raters and those rated have a clear understanding of the purposes and the techniques by which rating is to be accomplished. Too little attention has been given to proper education to introduce and assure the success of rating programs, although most rating sheets contain brief prefatory instructions which help to insure uniformity in procedure.

Almost without exception, those who rate are instructed to **deliberate in making ratings.** This is sound practice and is particularly productive of results when raters discuss among themselves the persons being rated. The discussion method is principally used, however, in modifying separate ratings already made privately, or when ratings are reviewed by the next higher official.

The purpose of rating is to minimize prejudice and bias so prevalent everywhere in subjective judgment. Every effort should be made not

only to present clear instructions but also to encourage deliberation and open discussion in order to provide a truly composite picture of an individual's real worth. The best results from a rating program will be obtained in those industries where adequate training courses and discussion groups consider rating from every possible angle. It should be the function of the committee in charge of the rating program to meet periodically with those who do the rating and provide opportunities for discussion of the program in use. Such discussion groups could be the nucleus for the development of a rating manual to be used by others less familiar with the rating program who may be called upon to participate in it.

Putting a Rating Program into Effect

INFORMING EMPLOYEES ABOUT THE PLAN.—All employees (shopworkers, supervisors, and executives) should be thoroughly acquainted with the factors by which they are appraised in order that they may make the best possible showing with respect to each. The method of weighting and scoring the rating form should be explained to them, and they should be allowed to criticize features of the rating form which they believe to be unfair. Furthermore, the success of the program is by no means certain unless those rated are given these assurances: (a) ratings are to be made fairly and without discrimination; (b) all ratings will be reviewed by impartial judges; (c) ratings will be used sincerely to assist the individual in developing his aptitudes to the greatest extent and increasing his worth to the firm, and never as a weapon of dismissal; (d) each man rated will be given a clear picture of his rating and an opportunity to defend himself if he is convinced that he has been treated unfairly.

DANGERS OF RATING.—The primary sources of danger in any rating program are the rater himself, the rating form, the frequency of making ratings, secrecy regarding the results, and inadequate education.

The Rater Himself.—The results to be achieved from any rating program can be no better than the judgment, honesty, and fairness of those who administer it. In order to protect persons rated against possible dangers which may arise in this connection, it is desirable that the rater be required to justify his ratings. Moreover, care must be taken to assure that ratings are always reviewed by superiors and compared with previous ratings.

The Form.—Too much care cannot be exercised in the selection of traits to be measured and the formulation of clear definitions. If such care is not exercised rating results are likely to be unsatisfactory. Forms should be printed attractively on paper so that those who are to rate will attach due importance to what they are doing. A mimeographed form has a bad psychological effect.

Frequency.—When ratings are made too often, they become irksome and the results suffer from haste on the part of the raters. The committee in charge of developing methods of rating must see to it that

ratings are made with sufficient frequency to be useful and comparable, but it must guard against too frequent ratings.

Secrecy.—The primary purpose of ratings is to correct shortcomings of those who are rated. Each employee rated is entitled to a frequent impersonal, constructive discussion of his rating. Unless such discussions take place, animosity and distrust will be aroused and forestall intended benefits for both top management and those who are rated.

Inadequate Explanation of the Plan.—Possibly the greatest danger to any rating program is lack of understanding of it's purposes and uses. No matter what amount of care is exercised in developing a system and how fair it is in execution, unless its purposes and intended uses are made very clear to those who are affected by it, the program will be enshrouded with mystery and give rise to suspicion and distrust. Such misunderstanding can only nullify the whole rating program.

Rating Plan for Shopworkers

SELECTION OF TRAITS.—One of the most difficult requirements of a committee on merit rating procedure is to select the traits which are to be used to measure worker performance. Problems encountered relate to the following: uniformity of definition, significance of relationships of the traits, and prevention of overlapping.

Traits commonly used to rate shopworkers may be grouped under **five** headings for purposes of clarity. These headings are:

1. Performance—traits which measure what the worker does on his job: accuracy or quality of work, speed or quantity of work, efficiency of use of working time, and job knowledge.
2. Potential—traits which measure the worker's aptitude, inherent abilities, ability to progress, intelligence, and leadership.
3. Behavior—traits which show the attitude of the individual, his influence on general morale, and application in his work: versatility, attitude, safety record, and attendance.
4. Employee factors—traits which are of importance in considering an employee's responsibilities and which represent the employee's point of view: citizenship, number of dependents, and length of service.
5. Personal factors—these traits include those which have a direct bearing on an employee's work through his attitudes and capacities for getting along with others: cheerfulness, initiative, loyalty, and enthusiasm.

These specific traits, listed in the foregoing general categories, may be reclassified again as objective and subjective, i.e., those which lend themselves to objective measurement and those which are purely matters of opinion. Traits which lend themselves to objective measurement are: accuracy or quality of work, speed or quantity of work, safety record, attendance, citizenship, number of dependents, and length of service. Traits which must be measured subjectively or appraised by judgment are: efficiency of use of working time, job knowledge (these may be reflected in accuracy and speed), intelligence, ability to progress, leadership, versatility, attitude, cheerfulness, initiative, loyalty, and enthusiasm.

SUGGESTED RATING SHEET FOR SHOPWORKERS.—All rating sheets are much alike but each represents the personal idiosyncrasies of those who have prepared it. For purposes of persons interested in checking existing rating plans, or inaugurating a new rating system, a rating form is reproduced which represents best practices of representative firms having rating programs in use. This form is shown in Fig. 6. It is a rating sheet which recognizes use of subjective and objective measures. The subjective part of the sheet (upper portion) may be filled in by a foreman, and when completed represents his opinion of an employee's attitude, initiative, leadership, etc. The sheet requires use of a stencil to score upper portion where traits are measured subjectively. A typical stencil for this purpose is shown in Fig. 7. As previously stated, the descriptions beneath the traits may be revealed in order, to run from good to bad instead of bad to good, for a few of the traits, to prevent the rater from tending to give about the same average rating for each of the traits.

The lower half of the sheet contains objective measures and may be completed by clerks in the personnel department, or in the office of the person in charge of rating. Objective measures used are: quality, quantity, citizenship, dependents, service, accidents, and absences.

COMPUTING POINT VALUES FOR FACTORS.—The means of computing point values for each of these factors is as follows:

Quality.—Determination of the score for quality depends largely upon the detail of spoilage records available. Where records are complete, a **spoilage median for each job** should first be figured. By dividing each employee's per cent spoilage into the per cent normal, and subtracting from the per cent normal, a per cent deviation for each employee is obtained. This figure should be entered on the rating sheet.

To convert this figure into rating points, a chart similar to Fig. 8 may be constructed. To secure rating for an employee working with material valued at 60 cents per unit, whose deviation is −4%, the scoring clerk looks at the intersection of the vertical column at −4 and the horizontal column at 60, obtaining a rating of 50. By use of this table, an employee who saves the company money by reducing the spoilage below average for his job will be rewarded in proportion to value of the material with which he works.

The primary difficulty encountered in the foregoing procedure is in determining the employee's median spoilage. To reduce the amount of clerical work necessary to obtain this number, it may be computed for a typical week or a group of days selected at random. If the number varies from the normal by a large amount, in fairness to the employee another sample should be taken to check the first.

Quantity.—The same problem must be solved in computing the median production of the employee for the period. After this median production has been calculated, a per cent efficiency may be obtained by dividing this number by the standard production, and the corresponding rating can be figured from a curve like that in Fig. 9.

Citizenship.—In the evaluation of citizenship, the employee is given 10 points if a citizen of the country and none if not. If desired, this rating may be broken down and a credit of 5 points given if the employee has taken out his first papers.

RATING SHEET

EMPLOYEE ________ CLOCK NO ________ JOB NO ________
FOREMAN ________ DEPT ________ DATE ________

CONSIDER HIS REACTION TO SHOP LIFE AND HIS EFFECT ON THE GENERAL MORALE IN THE FOLLOWING CIRCUMSTANCES

SCORE

1 ATTITUDE TOWARD COMPANY

actively antagonistic — passively antagonistic — cooperates passively — cooperates actively ✓

2 ATTITUDE TOWARD SUPERIORS

disregards wishes — follows orders but grumbles — follows orders cheerfully — tries to help make good ✓

3 ATTITUDE TOWARD FELLOW EMPLOYEES

puts blame for errors on them — looks down on them — helps them when told ✓ — extremely considerate

4 OBSERVANCE OF SAFETY RULES

openly disregards — believe disregards when not watched — observes all major rules — observes all and has own ✓

CONSIDER HIS ABILITY TO PLAN FOR HIMSELF AND TO EXECUTE SUCH PLANS

lives in a rut — has few suggestions — offers many suggestions, some good — offers many suggestions, many good ✓

CONSIDER THE DEGREE TO WHICH HE FAVORABLY INFLUENCES THE THOUGHTS AND ACTIONS OF OTHER EMPLOYEES

follows — thinks for himself, lets others do likewise — helps mold opinions of small group — has wide influence ✓

	RATING
QUALITY	50
QUANTITY	75
CITIZENSHIP	10
NUMBER OF DEPENDANTS	15
SERVICE	22
ACCIDENTS	40
ABSENCES	18

TOTAL → 230

PUT REASONS FOR RATINGS ON OTHER SIDE

FIG. 6. A Representative Employee Rating Sheet

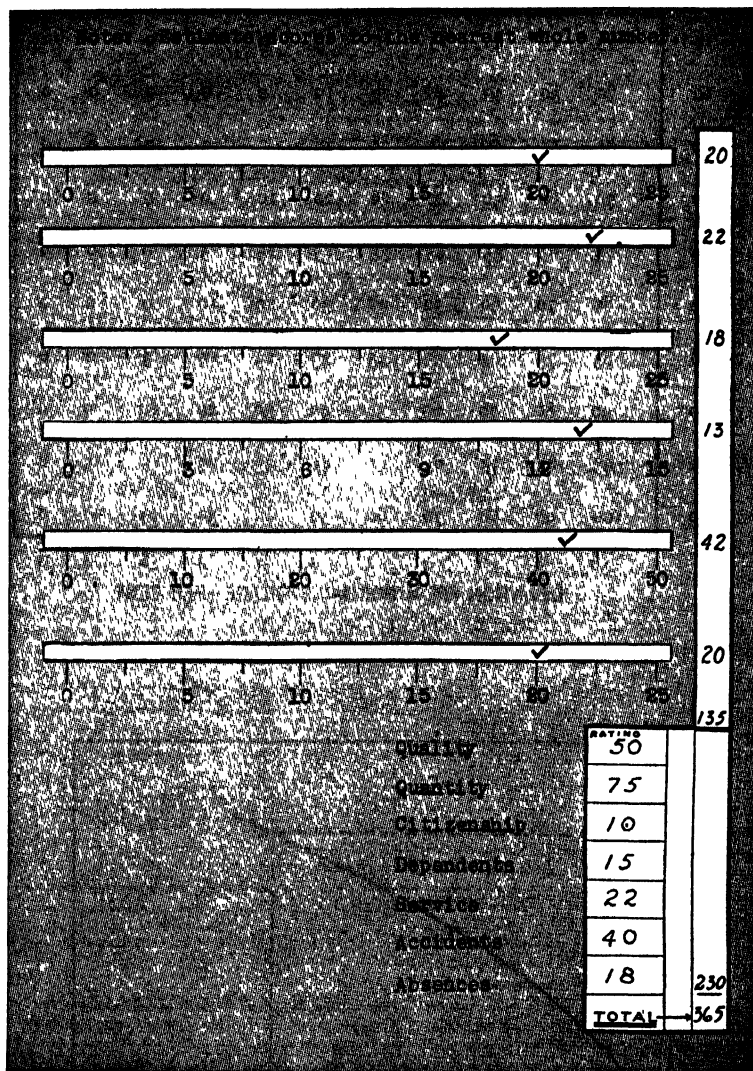



Fig. 7. Stencil to Check Employee Rating Sheet of Fig. 6

VALUE OF MATERIAL—CENTS PER UNIT \ DEVIATION FROM NORMAL SPOILAGE—PER CENT	−10	−8	−6	−4	−2	0	2	4	6	8	10
10	55	45	35	25	15	5	0	0	0	0	0
20	60	50	40	30	20	10	0	0	0	0	0
30	65	55	45	35	25	15	5	0	0	0	0
40	70	60	50	40	30	20	10	0	0	0	0
50	75	65	55	45	35	25	15	5	0	0	0
60	80	70	60	50	40	30	20	10	0	0	0
70	85	75	65	55	45	35	25	15	5	0	0
80	90	80	70	60	50	40	30	20	10	0	0
90	95	85	75	65	55	45	35	25	15	5	0
100	100	90	80	70	60	50	40	30	20	10	0

Fig. 8. Quality Scoring Chart

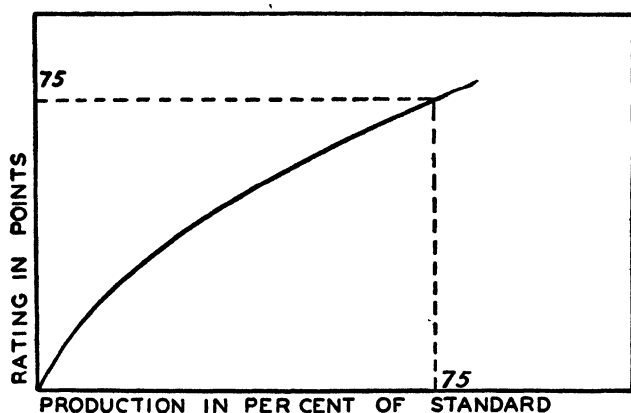



Fig. 9. Chart for Quantity Scoring

Dependents.—The score for the number of dependents may be taken from the following table:

No. of Dependents	Score
0	0
1	10
2	15
3	20
4	25

Service.—The score for the number of years' continuous service is taken from a table similar to the following:

No. of Years	Score	No. of Years	Score
0	0	6	15
1	2	7	17
2	5	8	20
3	7	9	22
4	10	10	25
5	12		

Accidents.—Scoring table for number of accidents chargeable to the employee may be constructed as follows:

No. of Accidents	Score
0	50
1	40
2	25
3	5
4 or more	0

Absences.—Score for number of unexcused absences may be based upon a table such as the following:

No. of Absences	Score
0	25
1	22
2	18
3	13
4	7
5 or more	0

Rating Plan for Supervisors

APPRAISING FOR LEADERSHIP.—Supervisor rating is comparatively new. Every progressive manager recognizes that where competent shop leadership is lacking, it is impossible to achieve maximum efficiency. Regardless of care exercised in selection of supervisors, the acid test of the value of each to his employer is demonstrated in job competence. Consequently, the use of merit rating systems is a definite aid to management in appraising the effectiveness of a supervisory force.

The term "supervisor" in this connection includes gang bosses or leaders, foremen, superintendents, department heads, department man-

agers, and even top executives of industrial concerns—in brief, **anyone who is responsible for the work of others.**

SELECTION OF TRAITS.—In selection of traits by which to measure supervisors, it is necessary to keep in mind that the supervisor is responsible for both his own work and the work of others. Factors of most concern to management regarding any person in a supervisory capacity may be grouped under three major headings.

1. **Personality.** Those factors that have to do with capacities for working cooperatively with others: appearance, ability to get along with others, character, intelligence.

2. **Performance.** Traits which bear directly on what the supervisor does on his present job: present productivity (use of own working time), productivity of unit for which supervisor is responsible, personal efficiency in completing work, and efficiency of unit for which responsible.

3. **Executive Capacities.** Traits which show potentialities of growth: initiative, organizing ability, leadership, and cooperation.

APPLICATION OF SUBJECTIVE AND OBJECTIVE MEASURES.—For the most part, supervisory rating must be done subjectively, various individuals must attempt to express their judgment of how well supervisors fill their jobs. Unfortunately, supervisor rating does not lend itself so readily to objective measures as does the rating of shop workers.

In this connection, some executives have suggested that supervisory and junior executive performance and capacities might be measured more specifically if provision were made to determine the **degree to which supervisors meet standard costs** as established for work which they do themselves or for which they are responsible. There is no doubt that demonstrated ability of supervisors and junior executives to keep actual costs in line with recommended or established standard costs is a fair indication of a type of efficiency, particularly in those organizations where standard costs have been in use for a considerable period and are therefore entirely fair (Knowles, Personnel, vol. 17). It is significant, however, that few concerns appear to recognize comparison of actual and standard costs as a measure of effectiveness of supervisors in their jobs, except as it may be considered indirectly in gaging quantity and quality performance.

Certain objections to using comparisons of actual and standard costs as measures of performance and ability are:

1. When supervisors are subject to appraisal on the basis of their relative abilities to keep within the bounds of established or recommended standard costs, they are immediately dependent on the whims and accuracy of the accounting department. For example, accountants do not always agree on the classifications of expenses, and standard costs systems will vary from plant to plant, and even among subsidiaries of a single organization. An appraisal of the results achieved by supervisors through comparison of their actual cost records with standard costs may lead to unfair criticisms and conclusions.

2. Many industries where supervisor rating is sorely needed do not lend themselves to effective use of standard cost systems. This is particularly true of industries that must constantly retool, change product lines, etc. Standard cost data either do not exist or are not sufficiently reliable to justify use in a rating system. Concerns having no standard costs and considering the adoption of supervisor rating might be less inclined to adopt it if it appeared to involve the establishment of a standard cost system.

3. A standard cost system can never measure the abilities needed to cope with the imponderables which arise in handling people and unusual events, which are perhaps the most important items to measure in a supervisor rating program.

SUPERVISOR RATING SHEET.—A supervisor rating form is shown in Figs. 10a and 10b. With minor modifications to suit particular needs, the form might be used for any or all of the following:

1. Measurement of how well supervisors fill their present positions; and to call attention to individual weaknesses that can be corrected.
2. Selection and guidance of men for promotion; in particular those capable of filling executive posts.
3. Guide in determination of supervisors' salaries.
4. Calling attention of management to particular factors in individual cases, i.e., special abilities, capacities for special job assignments, etc.
5. Providing information of value in deciding upon transfers.

The form is to be filled out by the immediate superior of the person rated and by fellow supervisors at semi-annual or annual periods. Instructions for using the rating form appear at the beginning of the sheet, and are numbered to correspond with the columns. In column 1 the person rated is checked as Superior, Above Average, etc., with respect to the traits listed. Column 2 provides space for recording the rater's observations of weaknesses or shortcomings of the individual under each trait. These remarks will prove helpful when referring to the form at some later time, and serve indirectly as a means of **justification of each rating.**

Provision is made in column 3 for weighting each trait as essential, desirable, or unimportant to the particular job held by the supervisor being rated. Column 4 records the total point rating, calculated by multiplying the assigned weights by the rating values shown under instruction 4. In keeping with desired practice, column 5 provides space for the personnel department review of the ratings.

The rating sheet demands that supervisors be rated on a scale ranging from 8 points for Superior to 0 for Unsatisfactory, and weighted as Essential, 4; Desirable, 3; Unimportant, 2. These values are not intended to be accepted universally by companies as fitting all needs; they should be used only as a guide for those who are undertaking the establishment of a supervisory rating program. The point values and weights used by various companies having supervisor rating programs are meaningful only as they are carefully defined by those who use them.

Besides providing for the rating of supervisors as individuals, the rating sheets must also be used in **making comparisons of the ratings of the respective supervisors.** Otherwise the records would prove of little value. For the latter purpose it is necessary to convert the total weighted-point score in each case to a percentage basis and to classify

supervisors according to their relative percentage scores. Since ratings depend somewhat on the judgment of the raters, and are made by different persons, the percentages must be zoned for equitable classification of the supervisors. Fig. 10b shows typical zones for five gradings from Superior to Unsatisfactory, with the percentage range allotted to each.

The determination of a supervisor's percentage rating from data in Figs. 10a and 10b is made as follows. The form weights each trait according to its importance from the standpoint of the supervisor's job. This weighted importance from the job viewpoint must be eliminated to make the ratings comparable among supervisors. The adjustment is made by multiplying the **sum of all the weights in column 3,** ΣW, by 8, the **maximum possible rating,** R, for each point, to obtain the **total point rating** $8 \times \Sigma W$ for a supervisor who would be "superior," or 100% efficient, in every respect in his job. Then, dividing this value into the **sum of the point ratings column 4,** or $\Sigma(R \times W)$, gives the supervisor's percentage rating relative to his **performance** on his job:

$$\text{Percentage rating} = \frac{\text{Total point rating (col. 4)}}{\text{Maximum possible point rating}} = \frac{\Sigma(R \times W)}{8 \times \Sigma W}$$

When supervisors' ratings have been reduced to a percentage basis as above, the over-all rating scale set up on a basis similar to that shown on Fig. 10b may be used to show into which group each individual supervisor classifies.

USES OF COMPLETED SUPERVISOR RATING FORM.—Primary uses of the rating sheet are: (1) to uncover and correct individual weaknesses, (2) to select men for promotion, (3) to pick out men for special assignments, (4) to compensate individuals on the basis of their qualifications for the various positions instead of general preferences expressed by department heads, and (5) to bring about a trend toward higher efficiency throughout the entire organization. (Job Evaluation and Merit Rating, Knowles, in Ten Years' Progress in Management, Trans. A.S.M.E., vol. 65).

Column 2 of the rating sheet in Fig. 10a provides opportunity for recording subfactors which define each of the traits listed and to clarify or give certain details regarding the qualifications which are unsatisfactory or lacking in the person rated. These weaknesses are naturally reflected in the effectiveness with which supervisors fill their jobs. The weaknesses should be made known to the supervisors in order that they may endeavor to improve their worth to their employers.

The rating sheet also provides valuable information which can be used to determine the promotional potentialities of supervisors. The following steps of a clerical nature are requisite to achievement of this end:

1. Standard weights for each trait as related to a specific supervisory job should be established. The weights recorded for the traits listed on the rating sheet show what raters believe to be their relative importance to the supervisory position. These figures should be used to establish composite **standard weights,** which will be different for each supervisory position under consideration.

RATING REPORT FOR SUPERVISORS, FOREMEN, AND DEPARTMENT HEADS

Name.................. Division.................. Date........

Position............... Department............... Code........

Note: Numbers in instructions correspond to column head numbers.

1. Read carefully the descriptions of the traits to be evaluated under each heading. Place a check mark in Column 1 under the heading of the division which most nearly expresses your considered judgment of each trait as applied to the person you are rating, i.e., Superior ( ), Above Average ( ), etc.

2. List in Column 2 those considerations stated under each trait which you believe to be deficiencies or weaknesses of the individual you are rating, i.e., neatness, voice, etc. Correction of the items you list will improve the individual's rating for this trait.

3. Each trait does not have equal bearing on all positions. To assure greater usefulness of the final results, raters must state their considered opinions of the relative significance of each as requisite to the job now held by the person rated, i.e., appearance, ability to get along with others, etc. Post in Column 3 the weight you accord each item as follows:

For items:	Assign weight of:
Essential to fill position properly	4
Desirable to fill position properly	3
Unimportant to fill position properly	2

4. To determine the point rating for each trait ($R \times W$), multiply the point value of the rating recorded in Column 1 by its assigned weight in Column 3 and post in Column 4. Rating values are as follows:

Superior	8	Average	4
Above Average	6	Below Average	2
Unsatisfactory	0		

5. Column 5 is for use of the Personnel Department in reviewing and regrading point ratings.

Do Not Fill in This Space

Rating Summary:

I. Personality ....

II. Performance ....

III. Executive Capacities ....

Over-all Rating Scale

(Expressed as percentage of total possible score)

88–100..................Superior

63– 87..................Above Average

38– 62..................Average

13– 37..................Below Average

0– 12..................Unsatisfactory

Total Point Rating:

Rated by...................... Reviewed by......................

Position .... Filed.............date

FIG. 10a. Rating Sheet for Supervisors

(A. S. Knowles)

	1					2	3	4	5
	Superior	Above Aver.	Average	Below Aver.	Unsatis.	Remarks	Weight	Point Rating (R x W)	Review
I. Personality:									
(a) Appearance. Consider dress, manner, physique, neatness, voice.									
(b) Ability to get along with others. Consider courtesy and tact, temperament and self-control.									
(c) Character. Consider dependability, sincerity, courage, and consideration for others.									
(d) Intelligence. Consider ability to learn, mental alertness, judgment, imagination, flexibility in handling new problems, ability to reason logically.									
Total Personality Point Rating:									
II. Performance:									
(a) Personal productivity. Consider use of own working time and amount of work done personally (not by unit for which person rated is responsible); consider also diligence in fulfilling duties.									
(b) Productivity of unit for which responsible. Consider amount of output or accomplishment of satisfactory quality.									
(c) Personal efficiency. Consider promptness in completing work for which person rated is personally responsible;]care and accuracy in completing necessary records and reports.									
(d) Efficiency of unit for which responsible. Consider economy in operation; prevention of waste of material, time and equipment; accident record of subordinates; care and orderliness of equipment and tools.									
Total Performance Point Rating:									
III. Executive Capacities:									
(a) Initiative. Consider energy, ingenuity, self-starting ability.									
(b) Organizing ability. Consider ability to select effective personnel, to plan and coordinate systematically, to determine policies, and make clear assignments of responsibility and authority.									
(c) Leadership. Consider ability to influence others by examples of good work, qualities for inspiring others, teaching ability, patience and firmness in dealing with subordinates, freedom from prejudice and bias.									
(d) Cooperation. Consider capacities for teamwork, freedom from jealousy, willingness to subordinate personal desires, loyalty to fellow supervisors, company officials, etc.									
Total Executive Capacities Point Rating:									

FIG. 10b. Rating Sheet for Supervisors (*continued*)

2. The **point ratings** for each trait given supervisors by raters in checking column 1 should be averaged separately. The average score for each trait should be entered on a permanent file copy.

3. When occasion arises to select a man for promotion or transfer, the data compiled in steps 1 and 2 can be used in conjunction to determine which supervisors are best suited for the positions involved: the **point ratings** of supervisors can be multiplied by the **standard weights** established for the traits as related to the particular position. This will give a score which can become an important guide in determining the degree to which each supervisor may be expected to meet the qualifications demanded by the position to be filled.

Thus, completed ratings may be used to advantage in aiding ambitious employees who wish to prepare themselves for positions above their present rank. As indicated, multiplication of any supervisor's point ratings by standard weights assigned the traits requisite to fill positions above his rank provides a tool by which top management may give intelligent guidance to subordinates. Careful study of the resulting scores will indicate the kind of work for which each supervisor is best suited, and, consequently, the training that he should undertake.

SECTION 18

WAGE PLANS

CONTENTS

PAGE

Supplementary Incentives

Selection of Financial Incentive Plans

PAGE

Financial Incentive Plans for Indirect Production

Financial Incentive Plans for Supervisors and Executives

Nonfinancial Incentives

SECTION 18

WAGE PLANS

IMPORTANCE OF WAGE INCENTIVES.—

"Wage Incentives, together with the tools of measurement, analysis and appraisal, have taken an important place in the industrial world." (Horning, N.I.C.B. Studies in Personnel Policy, No. 19.)

"The wage incentive is recognized as one of the most potent and dependable stimulants to increased production of wealth." (Lum, Mech. Eng., vol. 60.)

"It will be a good investment for management to examine its financial incentive plans critically at this time. If the employees are dissatisfied with a given plan, then there is likely to be something wrong, either with the plan itself, its installation, or its administration. Financial incentive plans have been applied successfully to all classes of positions in a company." (Bergen, A.M.A., Personnel, vol. 14.)

These statements regarding wage incentive plans indicate the importance they have attained in management and incidentally indicate the new nature of the problems now confronting those in charge of production. No longer is it a question whether they might help, but rather of how far should they be extended and what kind of a plan and procedure would be best for each set of conditions. It is the purpose of this Section to seek answers to these questions. These answers lie in the **use of correct principles**, not in the application of any particular rule. Hence, a rapid review of the whole development is necessary to cope properly with these problems.

ORIGIN OF PLANS.—Nearly every type of earning arrangement had been tried in either France or England long before the present plans were reinvented in the United States. European plans were never very successful, however, because they were applied to either guessed or bargained standards of production. Technique of task improvement and task measurement, that is, **job standardization,** as developed in the United States by Taylor and his associates, makes such plans successful, and consequently engineers of this country have been given the whole credit for their origination. It is true that one of these plans, the Halsey Premium or Constant Sharing plan, did have a certain success before the advent of "time study," but it started as a low-slope earning curve, one-third of sharing to employees, and brought neither a great increase to employees nor a great risk to employers, a condition then and now most suitable for "estimated" tasks and minor effects. Furthermore, the date of the Halsey plan, 1890, was only five years before Taylor's epoch-making paper, "A Piece Rate System," so that it was soon supported by awakened interest.

During the next 20 years, **interest in incentive plans** exceeded interest in job standardization. It was the "efficiency expert" period and the major trick was the incentive plan. Each expert would contrive a slightly different earning curve, label it with his own name, and apply it to all conditions, usually without improved tasks or adequate supporting measures. Despite discredit resulting from this patent-medicine type of practice, much experience was gained and a better era was begun. Dennison (Recent Economic Changes, vol. 2) says of 1921: "In that year more than 300 articles appeared telling of methods used in cutting wages and speculating as to how far they would fall. By 1922 articles of this sort had disappeared and those about wage incentives had taken their place." There also appeared a new discrimination and a **technique of analysis** regarding the principles and characteristics of the plans (Lytle).

Analysis of Wage Incentives

Type of Plan Used	Number of Employees on Plans	Per Cent of Those on Plans to All Employees	
1. Ordinary time rates	143,993	38.2	
2. Individual piece rates	112,977	37 2	61.6
3. Group piece rates	27,005		
4. Individual premium or bonus	41,031	19.0	
5. Group premium or bonus	30,613		
6. "Measured day rate"	20,312	5.4	
7. Unclassified	902	.2	
Total	376,833	100.0	

Collecting items (2) and (4): 40.9% participate as individuals.
Collecting items (3) and (5): 15.3% participate in groups.

Analysis of 265 of the 313 Companies, Arranged by Groups According to Per Cent of Employees on Incentives

Number of Companies	Per Cent of Employees on Incentive
14	Less than 25
15	25 – 49
149	50 – 74
72	75 – 89
15	90 and over

Analysis of the 313 Companies Arranged as to Size

Number of Companies	Number of Employees	Per Cent on Incentive
30	Less than 250	55.7
64	250 – 499	61.8
96	500 – 999	65.2
47	1,000 – 1,999	64.0
23	2,000 – 2,999	62.1
27	3,000 – 4,999	64 5
13	5,000 and over	54.2

FIG. 1. Analysis of Wage Incentives in 313 Companies

STATISTICS ON EXTENSION OF INCENTIVES.—The most reliable data on extent to which wage incentives were applied up to that time comes from a 1940 survey of 2,700 companies by the Nat. Ind. Conference Board (Studies in Personnel Policy, No. 19). These companies represented all kinds and sizes of business in the United States, and employed approximately 5,000,000 workers. Of these miscellaneous companies, 51.7%, employing 2,655,000 workers, used wage incentives. The survey covered 900 manufacturing companies ranging in size from 100 to 10,000 workers. Of these manufacturing companies, 75% used wage incentives. Selecting the 313 companies which furnished more specific information, 60.3% of employees who were on some incentive plan were on piece-rate plans (48.7% as individuals and 11.6% in groups). Of employees on some incentive, 30.9% were on various premium or bonus plans (17.7% as individuals and 13.2% in groups). The remaining 8.8% of those on incentive were on "measured day rate," no distinction between individual and group application being reported. Counting all employees, 376,833 in the 313 manufacturing companies, 61.6% were on some form of extra-financial incentive, against 38.2% on ordinary time rates and .2% unclassified. Another survey of 200,000 factory employees showed that, in 1938, 80% of direct labor was on incentives and getting 14% more than those on time payment. (See Fig. 1.)

From these analyses, it appears that **company size makes no material difference** as to use of incentives. A further fact is that there appears to be no tendency for any few particular plans to supplant the many plans that have been put into use.

WARTIME SURVEY.—The American Management Association (May, 1943) made a sampling survey including 50 representative manufacturing companies. The answers showed that:

1. 62% of direct producers and 17% of indirect producers were being paid extra-financial incentives. Of direct producers, 48% were on an individual basis and 30% were on a group basis. Of indirect producers, 23% were on an individual basis and 32% were on a group basis.
2. 70% of the 50 employers said that the percentage of their incentive-paid employees to time-paid employees had not changed since 1939. The remaining 30% said the percentage had changed. 85% of employers had not changed their plans since April, 1939.
3. Sorting by kind of plan used: Piece-rate, 28%; standard hour, 23%; together, 51% equivalent to piece-rate. Bedaux, 17%. Halsey and other premiums, 17%. All other kinds of plans, 15%.
4. Half of the companies reported employee efficiency as above 100%; highest case, 150% above; lowest case, 15% above. 73% of the companies said that efficiencies had not changed since Pearl Harbor. Remaining companies said efficiency had changed, some up, some down. Comments from these companies:

   "In each case where we have changed from daywork to incentive, we have increased the man-hour output 20% to 30%."

   "Many machine operations have shown over 50% increase in output—especially valuable at this time."

   "Incentive piecework is effective on continuous mass production."

   "Recently union has voted 10 to 1 to restore incentives."

Basic Objectives of Wage Incentives

COMMON INTEREST OF MANAGEMENT AND WORKERS.—In general terms, the objective of any wage incentive is to arrange an efficiency earning agreement through which the interests of management and employees will coincide. These interests rest upon specific conditions, some of which can and should be changed in **preparation for an incentive installation,** but other conditions, inherent with the type of labor, materials, or even with the company, may not be open to change. Separating the unalterable from the alterable conditions is, therefore, the first consideration. With basic conditions analyzed, it should be a simple matter to ascertain what the specific interests are, and whether or not they all fall within the limits of company policy. If they do not, perhaps the policy should be revised. Any major change in regard to use of tasks and incentives should be checked at this stage by top management, and the personnel director if one is employed. Union leaders should also be brought into council (Incentive Wage Plans and Collective Bargaining, Monthly Labor Rev., vols. 55 and 56.

Since the advent of **reliable job evaluation** there has been a tendency to derive piece rates and other incentive rates from time rates on the same or equivalent jobs. This is good practice if equivalency is well established. Incentive jobs might well be subjected to the same thorough evaluation that time-rate jobs are now getting in well-managed companies. Such rate setting would likely be more just and permanent than any other. Furthermore, such thorough evaluation would facilitate shifting back and forth from one method of payment to another as is often necessary in small departments.

The older practice, of assuming from experience the amount an operative can be expected to earn at a particular incentive job, and then working back to determine the rate, is still in use. This method not only lacks scientific foundation but is open to criticism that the management is limiting the earnings to some preconceived amount per week. Even so, an efficient worker often exceeds the preconceived earning and is allowed to continue doing so if the management is enlightened. In either case the company should formulate a basic policy for estimated incentive earnings. Earnings may range anywhere between the necessary hiring rate per week and the allotted amount of labor cost which the business can afford to pay per week, up to an unwarranted sacrifice of gross profits.

INCENTIVES AND ECONOMICS.—What the factory can afford to pay can be determined only by considering the whole economics of total cost as that is affected by volume of business. If it is assured that **use of a strong incentive will increase the efficiency of production,** say 25%, then a fifth of the employees might be dismissed, or working hours might be shortened a fifth, or 25% more goods might be produced. The time and motion study that is done in preparation for incentives can be relied upon to reduce, in potentiality, labor cost per unit of product. The proper incentive then acts as an enforcement of this potential saving, and, in addition, achieves an increase in volume of production which brings a saving in overhead cost per unit of product and a net saving in total cost per unit. A reduction in selling price is thus possible, or, if that is uncalled for, the gain from improved overhead

distribution might go to plant improvement, plant extension, or to increased profits.

If these various outlets do not require all the gains, then the company can afford voluntarily to increase its wage rates. Many companies, through incentives and accompanying activities, have been able to provide for all these gains. Naturally, this whole process depends upon volume of sales orders which a company can budget. This volume, in turn, depends on competitive conditions, stage of business cycle, impositions of government, etc. But whether a business needs to increase volume to keep up with orders, or to decrease costs to meet price competition, it can usually make further reductions: in labor cost through time and motion study, and in overhead cost through incentives. In short, the use of improved tasks and better incentives can be helpful in either prosperous or unprosperous times. Furthermore, there is no end to these potential gains.

Strange as it may seem, **highly developed plants are as likely to find further gains** as are poorly developed plants. Finally, incentives can be applied successfully wherever there are established tasks; conversely, no incentives can be applied successfully where there are no established tasks. Improvement in methods, tools, and motions that comes during the establishment of correct tasks makes possible an improvement in labor efficiency and labor cost, but it is the incentive that releases human energy and cooperation, thereby making these potential gains effective day-in and day-out, so that overhead charges per unit of product may be lowered through volume.

Fundamental Factors

DEFINITIONS.—The definitions which follow are important to establish a clear understanding of terms used in the subsequent discussion.

> **Wages** are the aggregate earnings of an employee for a given period of time such as a day or week, and are equal to the product of hourly rate times number of hours, or the product of piece rate times number of pieces, plus any premiums or bonuses earned.

These earnings may be expressed in money, in which case they are called **nominal wages,** or in goods and services purchasable with money, in which case they are called **real wages.** It is important not to confuse wages with wage rates, or nominal wages with real wages.

The term **incentive** is general and includes all influences, positive and negative, which stimulate human exertion. In industry incentives may be divided into financial and nonfinancial. **Financial incentives** include broadly any form of wage, salary, premium, bonus, prize, or return on investment. Excluding ordinary time wages and ordinary return on investment, **extra-financial incentives** embrace all "payment by results" plans. More specifically,

> **Extra-financial incentives** are remuneration arrangements which provide money inducements, other than base time or overtime wages, for the accomplishment of definite quality-quantity-economy standards, i.e., tasks.

For purposes of clarity, the symbols used throughout this Section are briefly defined and illustrated in the **General Key to Symbols** as they are employed in the remaining definitions and in the equations for the various wage incentive plans.

General Key to Symbols

E = **Earnings in Dollars (a Variable)**
R_h = **Rate per Hour in Dollars** ($.48 in specific cases)
R_p = Rate per piece in dollars ($.16 in specific cases)
R_t = Rate per time unit longer than an hour, also
  Sub. d = per day
  Sub. w = per week
  Sub. m = per month
  Sub. y = per year
H_a = **Hours Actual** (made **Constant** for a day of 8 hr.)
H_s = **Hours Standard** (made **Variable,** inverse to efficiency)
H_{sl} = Same as above for low task on standard abscissas
H_{sp} = Hours standard per piece
N_p = Number of pieces produced, $N_{pd} = N_p$ per day
B = Guarantee rate in per cent of standard or going rate R_h (Base). B may be unity and not appear.
B_o = Bonus in per cent of $B\ H_a\ R_h$, a constant. $B_{od} = B_o$ per day
P_r = Premium in per cent of $(H_s - H_a)\ R_h$, a variable. $P_{rd} = P_r$ per day
I = Incentive portion of E, viz., $B_o + P_r$
F = Factor of labor's share in per cent of time saved
W = Wages in per cent of standard at task efficiency

Only a few of these symbols are necessary for most of the formulas and they may be learned by use in a few seconds. For instance, by definition:

(1)	Piece rate earning	=	No. of pieces	×	Rate per piece
	E	=	N_p		R_p
(2)	Time rate earning	=	Hours actual	×	Rate per hour
	E	=	H_a		R_h
(3)	Time saved	=	Hours standard	−	Hours actual
	(no symbol)	=	H_s	−	H_a
(4)	Wages saved	=	Time saved	×	Rate per hour
	(no symbol)	=	$(H_s - H_a)$		R_h

The four symbols with definitions in boldface are the most important, in fact are the only ones essential to most of the discussions.

From two expressions, (2) and (4), in the General Key to Symbols nearly all incentive formulas are derived, for instance:

$H_a R_h + (H_s - H_a)\ R_h = H_s R_h$, or unity piece rate expressed in hours of standard task

Constant sharing plans may be similarly expressed by inserting the correct arithmetical fraction in front of the binomial. For other piece

rates the fraction must precede both terms; thus, high piece rate becomes

$$1.20\, H_a R_h + 1.20\, (H_s - H_a)\, R_h = 1.20\, H_s R_h$$

Tasks, the immediate prerequisites of extra-financial incentives, are the standards of accomplishment per period of time primarily in terms of quantity per hour, hence called **standard hour** or **hours standard,** H_s, but usually including one or more additional requirements, such as product quality, material economy, or employee regularity, versatility, cooperation, loyalty and others.

Productive efficiency is ratio of the task amount of work, or hours standard, to hours actually taken, H_a, in performing the work, H_s/H_a. When H_a equals H_s, ratio becomes unity and the efficiency is at 100%.

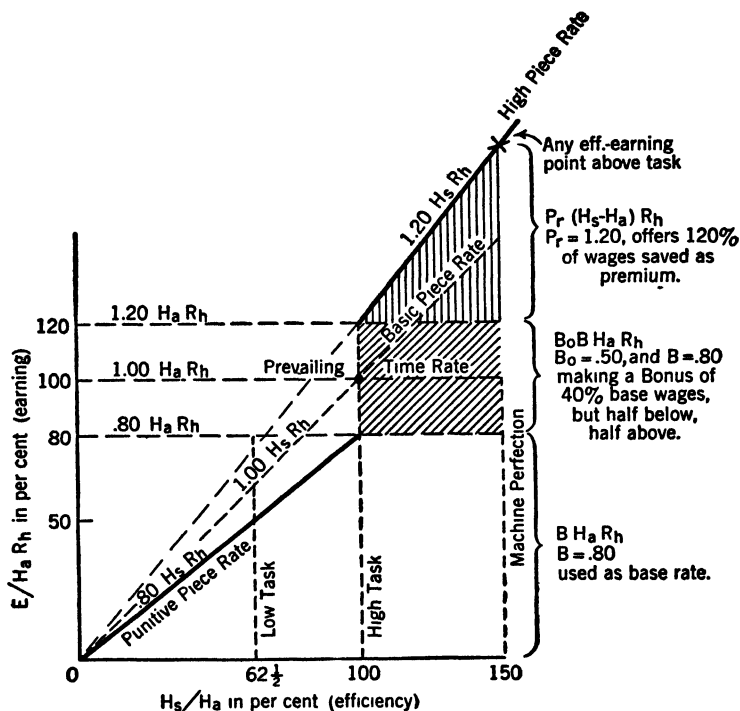
Because in practice tasks range into two broad classes, improved and unimproved, it is necessary to distinguish such difference by referring to the former class as "high task" and the latter as "low task."

High task, or 100% efficiency, is an amount of production derived through motion and/or time study which a normal operative can accomplish day after day without physical or mental impairment. It should be about two-thirds of machine perfection. Machine perfection refers to human operation which must continue constantly as a machine works, keeping up with full mechanical capacity. To achieve this perfection the operator must not miss a single cycle of the machine.

Low task is an amount of production derived by averaging recorded but not time-studied achievements made under time payment. It varies widely from one-third to one-half of the equivalent of machine perfection. Low task is assumed in these pages as 62½% efficiency.

Machine perfection means the full capacity of a mechanically driven but hand-operated machine. To get such potential capacity the operative must be as regular as the machine and never miss a single cycle of work. Experience puts such maximum productivity at about 150% of high task as defined above. On such a machine the rare, but well-known, superworker will approach machine perfection, averaging about 145% which would be the potential maximum of "high task." This upper limit provides, when available, a definite check on tasks, whether they are high, 100%, or low, say 62½%. This latter figure is taken arbitrarily as about the amount in usual practice and is just above discharge point, which is placed at 60% of high task.

Standard charts for earning curves show both tasks as particular locations on the abscissas, or horizontal scale, measuring productive efficiency H_s/H_a. Since this efficiency is expressed as ratio of hours standard H_s divided by hours actual H_a, then high task is 100% or unity times that ratio, 1.00 H_s/H_a, and low task is 62½% or .625 H_s/H_a. For a fixed earning curve, either the formula or the efficiency scale must be changed to permit a change of expression from one task to another. The present treatment avoids changing formulas and uses two horizontal scales so that comparisons may be made between all data and between all curves.

Time wages, already included under the definition of wages, will hereafter be expressed in hourly terms as hours actual H_a times rate per hour R_h, as $H_a R_h$, and any earning E divided by that factor is taken as the ordinate, or vertical scale, $E/H_a R_h$; 100% time wages, $B\, H_a\, R_h$, where $B = 1.00$, indicates the normal base wage per hour. In Fig. 2 these quantities are graphically portrayed. The plan first used by Taylor

Taylor Differential Piece-Rate Earning Curve in heavy line.

Formula for same, (below task) $E = \underset{(B)}{.80}\, H_s R_h = .80\, N_p R_p$

(above task) $E = \underset{(B)}{.80}\, H_a R_h + \underset{(B_o B)}{.40}\, H_a R_h + \underset{(P_r)}{1.20}\, (H_s - H_a)\, R_h$

Note $(B + B_o B) = Pr$

$.80 + .50 \times .80 = 1.20$

$= 1.20\, H_s R_h = 1.20\, N_p R_p$

FIG. 2. Standard Scales for Efficiency-Earning Curves
(Vertical shading represents premium earnings and inclined shading represents bonus earnings)

is plotted as a matter of historic interest. Prevailing time rate and basic piece rate are shown incidentally.

At point (100, 100)—the first number always refers to horizontal scale and the second to vertical scale—hours standard equals hours actual, $H_s = H_a$, efficiency H_s/H_a equals unity, time wages $H_a R_h$ has the coefficient of unity, and piece rate $H_s R_h$ has a coefficient or slope of unity. This slope is always the numerical coefficient of $H_a R_h$ divided by the numerical coefficient of H_s/H_a for any given point on the earning curve. Slope equals tangent of angle, or altitude divided by base. In taking slopes it is convenient to do so at 100% efficiency because there the denominator or base is unity and the numerator or altitude alone will give the measure. Thus, there are several reasons why **point (100, 100) may be called the basic point of the chart.** It is the natural "bench mark" for starting any graphic analysis of earning curves. Either H_a or H_s might be treated as a constant if the other were allowed to vary. In this treatment H_a is held constant at 8 hr. and H_s made to vary.

Bonus is that portion of earning, expressed in per cent B_o of B time wages, $B H_a R_h$, which at some fixed efficiency point exceeds the earning, B% of time rate $B H_a R_h$ arranged for a preceding point. It may be offered as an abrupt "step" in a series of steps for predetermined points of efficiency attainment. These steps vary in size and number from a single large step, as used by Taylor, to numerous small steps portrayed in a "bonus-efficiency" table. Thirty-two small steps were used by Emerson. Bonus also occurs, usually unrecognized but existing, as a part of high rates. Here it is the measure of excess earning over base wage, B equals 100%, at high-task efficiency, remaining constant while the premium increases for higher efficiencies. This "bonus" is a matter of mathematics only (see chart of Emerson plan, Fig. 23).

Premium is that portion of earning, expressed in some function (P_r) of wages saved, $P_r\ (H_s - H_a)\ R_h$, which exceeds normal time wages, $1.00\ H_a R_h$. When task or base time wage is other than unity, coefficients for H_s and H_a will not be identical. If the coefficient P_r is a numerical constant and more than, or equal to, unity, the result is the piece-rate plan. If it is a numerical constant but less than unity, it is a constant sharing plan, and the coefficient measures the employee's share of potential saving. If the coefficient is an algebraic variable, it is a variable sharing plan. In all cases where there is a bonus at task, the premium, if any, continues as a variable in addition to the constant bonus, but the two are not usually separated in the pay envelope or on the chart. However, they can be separated on the chart or by formula for purposes of analysis and comparison. The **combined amount of constant bonus and variable premium** may now be designated as **incentive,** I.

$$I = B_o B\ (H_a R_h) + P_r\ (H_s - H_a)\ R_h \tag{1}$$

This derives the **general formula for any earning,** E, as shown by its earning curve,

$$E = B\ H_a R_h + I \tag{2}$$

or substituting from (1),

$$E = (B + B_o B)\ (H_a R_h) + P_r\ (H_s - H_a)\ R_h \tag{3}$$

$$E = [(1 + B_o)\ B\ H_a + P_r\ (H_s - H_a)]\ R_h \tag{4}$$

and when P_r equals $B + B_o B$ the plan is a piece rate,

$$E = P_r H_s R_h \tag{5}$$

Profit sharing, when contingent on performance, belongs to the classification of extra-financial incentives but, because of its uncertain relationship to exertion, inclusion is provisional.

Nonfinancial incentives include all other influences planned or unplanned which stimulate exertion, as for instance, on positive side, promotion, training, records of performance, competitions, recognition, praise, honor, or merely good foremanship.

REDUCING PLANS TO CURVES AND FORMULA.—Any wage incentive plan (this is the accepted term for including ordinary time wages with the extra-financial incentive plans) must be definite and reducible to curve and formula. If its description is otherwise, the fault must be charged to poor wording, not to the plan. Descriptions in good prose always permit plotting two or more points between the standard scales. For straight-line earning curves they are enough to determine location of the whole line. If a plan is broken into more than one straight line, additional points are necessary. Since time-rate earning "curves" are by their nature horizontal on standard scales, it is necessary to know only the relation B of the rate per hour R_h to normal base rate per hour, 1.00 R_h.

Since **piece-rate earning "curves"** are by their nature straight lines passing through, or directed toward, the origin point (0, 0), it is necessary to know only one additional point or the slope for each piece-rate line. Piece-rate earnings may be figured by multiplying number of pieces N_p by rate per piece R_p, or they may be figured by multiplying number of standard hours H_s by rate per hour R_h [see equation (5)]:

$$N_p R_p = P_r H_s R_h = P_r H_a R_h + P_r (H_s - H_a) R_h$$

Piece-rate formulas will be kept in the latter terms in this treatment for ease of comparisons. Sharing plans, like piece-rate plans, involve the element of wages saved, $P_r (H_s - H_a) R_h$, in which P_r is either a fixed per cent, that is, a constant coefficient less than unity, or a variable coefficient. In the Barth plan, P_r becomes a wholly unrelated expression. The empiric earning curves require tables of corresponding bonus-efficiencies through midway points but are completely reducible to formulas on either side of such empiric points. Thus, from mere prose descriptions earning curves may be accurately plotted on charts and definitely expressed in formulas. Only four mnemonic symbols are necessary for most cases. These are: E, H_a, H_s, R_h, as already explained. Two arrangements of the formulas are helpful in analysis. For example:

TYPE A

	Unity time wage + P_r × Wages saved
1. Ordinary Time wages (zero terms inserted for comparison)	$E = H_a R_h + .00 (H_s - H_a) R_h$
2. 50–50 Constant sharing wages	$E = H_a R_h + .50 (H_s - H_a) R_h$
3. Rowan Variable sharing wages	$E = H_a R_h + \frac{H_a}{H_s} (H_s - H_a) R_h$
4. Basic Piece wages	$E = H_a R_h + 1.00 (H_s - H_a) R_h$

TYPE B

	Curve takes the form $y = (m \times x) \quad + b$
1. Ordinary Time wages (zero terms inserted for comparison)	$\frac{E}{H_a R_h} = 0 \times \frac{H_s}{H_a} + 1.00$
2. 50–50 Constant sharing wages	$\frac{E}{H_a R_h} = .50 \quad \frac{H_s}{H_a^1} + .50$
3. Rowan Variable sharing wages	$\frac{E}{H_a R_h} = \left(\frac{2H_a H_s - H_a^2}{H_s^2}\right) \frac{H_s}{H_a} + 0$
4. Basic Piece wages	$\frac{E}{H_a R_h} = 1.00 \quad \frac{H_s}{H_a} + 0$

By applying formulas the most dissimilar plans, excepting Barth, and Accelerating Premiums, are seen to derive from the same two parent quantities, time wages $H_a\ R_h$ as the basis of bonus, and wages saved, $(H_s - H_a)\ R_h$, as the basis of premium. Hence, **type A formulas are best for comparisons.**

By applying type B formulas, the slope m can be seen as the coefficient of the first item, and the vertical intercept b can be seen as the second item. When plotted and analyzed by these formulas, most of the characteristics of each plan may be discerned and accurately measured. Hence, **type B formulas are best for analysis.**

CLASSIFICATION BY EARNING CURVES.—From type A formulas it is obvious that ordinary time (1) lies at one extreme with a zero share of wages saved, and basic piece wage (4) is at the other extreme with 100%, or the whole "share" of wages, saved to employees. This provides a natural basis of classification. Thus, **time plans** may be called class I, in which employer takes all gain or loss in labor cost relative to standard performance; **piece-rate plans** may be called class II, in which employee takes all such gain or loss. As sharing plans fall between these two, it is necessary to establish class III, in which the gain, if any, is shared between employer and employees. If a fourth class is now established for plans eliminated by the three foregoing, there will be a class IV, in which there is empiric location of points between the two variables, efficiency and earning. While this class name describes exactly what is done in plans so classified, it needs to be noted that empiric points are usually within a certain zone rather than all the way from low to high performance. In Accelerating Premium plans, where hyperbolas and parabolas are used, the incentive varies and in some cases exceeds 100% sharing. Hence, it is necessary to constitute class V for these new plans (Lytle, Wage Incentive Methods, rev. ed.).

This natural classification of all financial incentive earning characteristics is given in greater detail in Fig. 3. Engineers frequently gave their names to plans which they originated. These are retained in this table, but are modified thereafter for sake of consistency and clarity.

A definite quantity-quality-economy standard must be established and enforced as a prerequisite to any of these plans except I, 1.

Class I. Employer Takes All Gain or Loss as to Labor Cost

1. Time: hour, week, or any straight salary rate. (Not an extra-financial incentive.)
2. Standard time using two rates, one either side of task. A two-zone multiple time plan.
3. Multiple time: arithmetic steps in rate between production zones. (Sometimes called standard time plan.)
4. Multiple time: geometric steps in rate between production zones.

Class II. Employee Takes All Gain or Loss as to Labor Cost

5. Piece or straight commission rate. (May be looked upon as the extreme case of multiple time. This may be subdivided into punitive, basic, and high.)
6. Taylor. (Multiple piece rate or multiple commission.)
7. Merrick. (Multiple piece rate or multiple commission.)
8. Gantt. (Combination of No. 1 and No. 5 with step between.) (Without step would be called piece rate with guarantee, Manchester, Standard Hour, 100% Premium or Haynes Manit. All five have identical earning curves. Some applications of Bedaux and Dyer also.)

Class III.† Gain Shared Between Employer and Employee but Day Wage Guaranteed, Excepting in Barth and Certain Modifications of Halsey

9. Halsey.*
10. Diemer.
11. Baum.*
12. Bedaux, Dyer, "F.A.M.," Keays-Weaver, "K.I.M.," Shanley and Stevens.
13. Ficker Time } (Awkward and unsound.)
14. Ficker Piece }
15. Parkhurst.
16. Rowan,* Mansfield,* and Bayle.*
17. Barth.* (Particularly good for beginners.)

Class IV. Empiric Location of Points Between the Two Variables

18. Emerson.
19. Wennerlund. (Piecework or commission above 100% production.)
20. Knoeppel.
21. Bigelow.
22. Bigelow-Knoeppel.
23. Ernst and Ernst.
24. Sylvester.

Class V. Accelerating Premium Plans

25. Hyperbolas } (Concave on upper side.)
26. Parabolas }

---

* Intended for old-fashioned management with low production standards.
† Nos. 9 to 15 are constant sharing plans, while 16 and 17 are variable sharing plans.
This classification was originally given by C. W. Lytle before Marketing Executives Division, No. 51, American Management Association, 1927.

Fig. 3. Classification of Wage Incentive Plans by Production Earning Characteristics

Analysis of Wage Plans

ALL PLANS REDUCED TO ELEVEN DISTINCTIVE FEATURES.—Many of the accepted plans are not sufficiently distinctive to merit their existence. Thorough analysis of 25 plans, with their further modified forms, allowed a selection of the features which are distinctive (Lytle, Mech. Eng., vol. 51). These separate, or original, features were reduced to 10 in number. One more is now added. They are presented here with formulas for earning (Figs. 4a and 4b). Where only a portion of a whole plan is considered distinctive, the formula for that part only is given. Each of these 11 plans is described as to its characteristics, suitable application, and other features in pages that follow. Further mathematical analysis is not included (Lytle, Wage Incentive Methods, rev. ed.).

TIME-RATE PLAN: DEFINITION.—

$$\text{Earning} = \text{Rate per period of time} \times \text{Number of periods}$$

See Figs. 5 and 6.

When an employee is hired on ordinary time rate basis, contract between the two parties is definite only in rate of pay per period of time. Amount of work to be rendered must depend upon net effect of employee willingness and employer supervision. The employee guesses at the amount of production below which he will be discharged, and at amount for which he might be given a raise. If the latter is less certain than former, as it frequently is, his tendency is to standardize his performance as close to the lower limit as seems safe. No matter how earnestly an employer may wish to deal justly, without carefully determined tasks, some employees will not do their best and those who may do so are likely to meet with delayed or inadequate recognition. **Discrimination in rates** can be used to reward versatility, cooperation, loyalty, seniority, etc., but when this has the appearance of unequal pay for equal work it may not be advisable.

It is true that tasks might be accurately determined for time-paid employees, but when tasks are accurately determined there is no further obstacle to using a more automatic incentive plan. Time rates are usually applied where tasks cannot be, or have not yet been, measured. For these **unmeasured jobs**, ordinary time rates are the only logical means of payment. If employees involved are sufficiently high-class, they may do reasonably well from promptings of honor, pride, or farsighted self-interest. Appeal to all of these and to kindred instincts is therefore important to the success of ordinary time rates. For employees who are unresponsive to such appeals, if there are such, a negative type of incentive may be necessary. Many a foreman has neglected nonfinancial incentives altogether on the fallacious reasoning that they are not effective for the lower grade of employees and not necessary for the higher grade of employees. The usual **response to time rates** is around 60% to 65% of high task which goes with most financial incentive plans; sometimes it is as low as 25%, at best it rarely exceeds 75%.

APPLICATION OF TIME-RATE PLAN.—Probably any job can be standardized if it is sufficiently important to do so. In many

1. **Day Rate Plan**—with production records and promotion
   For unstandardized work, permanent, or temporary.
   It is simple and seems to be the only plan possible where work is not measured.
   Management should eliminate unsupported daywork wherever and whenever possible.

2. **Differential Time Plan**—with high bonus step or steps
   For upgrading employees formerly on day rates, also for group applications.
   It is strong at task point and simple at all points.
   It must be more carefully managed than a more elaborate plan.

3. **High Piece-Rate Plan**—with or without a minimum guarantee and with time basis of computation
   For repetition work, not involving expensive machine rates.
   It is the simplest and the most sound of all plans within the limits of its application.
   Equalization requires care as task per unit of time may not be evident.

4. **Merrick Differential Piece-Rate Plan**
   For upgrading inefficient employees formerly on low piece rate.
   It is flexible, strong, and relatively simple for what it can do.
   Tables must be used for explanation as well as for computation.

5. **Gantt Task and Bonus Plan** (a combination of Nos. 1 and 3 with a step between)
   For machine jobs liable to delay and where machine rates are high.
   It provides security with strength.
   The day guarantee may need watching.

6. **Halsey (50-50) Constant Sharing Plan**—with time guarantee
   For guessed-at-standards, no big machine rates.
   It gives a high wage through intermediate production efficiencies.
   Task or rate inaccuracy is less serious.

7. **(40-60) Constant Sharing Plan as a Substitute for Time Guarantee**—up to 70% high task
   For beginners.
   It makes a simple and just plan for these limits with less earning than under day wage and more than under piece rate.
   It is probably easier to understand than the Barth plan for the same purpose. It is not recommended beyond 70% task.

8. **Bedaux Point Plan**
   For strongly centralized management and widely diversified operations.
   It gets results through its production control rather than through high rates.
   It involves much figuring.

FIG 4a. Plans Which Are Justified, for What, Why, and How

---

1. **Earning = Hours actual × Rate per hour**
   $E = H_a \quad R_h$

---

2. Up to high task, $E = H_a R_h$, as in No. 1
   Earning = Fraction × Hrs. act. × Rate per hr.
   From 100% of high task on, $E = 1.20 \quad H_a \quad R_h$
   For plans with several steps, one geometric series, see C. W. Lytle, Wage Incentive Methods

---

3. **Earning = Fraction × Hours standard × Rate per hour**
   $E = 1.33\frac{1}{3} \quad H_s \quad R_h$
   (or number of pieces × high rate per piece)

---

4. **Earning = Fraction × Hrs. std. × Rate per hr.**
   Up to 83% of high task, $E = 1.00 \quad H_s \quad R_h$
   Between 83% and 100% of high task, $E = 1.08 \quad H_s \quad R_h$
   From 100% of high task on, $E = 1.20 \quad H_s \quad R_h$
   (might change again at 110% and use No. 3)

---

5. Up to 100% of high task, $E = H_a R_h$, as in No. 1.
   Earning = Fraction × Hrs. std. × Rate per hr.
   From 100% of high task on, $E = 1.20 \quad H_s \quad R_h$ (as in No. 4)
   (or 1.33⅓ as in No. 3)

---

6. Up to 62½ of high task (low task), $E = H_a R_h$, as in No. 1
   Earning = Time wages + Fraction × Saving
   From 62½% of high task on, $E = H_a R_h + .50\,(H_s - H_a) R_h$
   (in modified form this fraction varies from .25 to .75. See next two.)

---

7. **Earning = Fraction of rate × Binomial**
   Up to 70% of high task, $E = \frac{R_h}{35} (14\,H_s + 21\,H_a)$
   From 70% of high task on, use another plan as No. 3 with slightly higher fraction.

---

8. Up to 100% of high task, $E = H_a R_h$, as in No. 1
   Earning = Time wages + Fraction × Saving
   From 100% of high task on, $E = H_a R_h + .75\,(H_s - H_a) R_h$

Fig. 4b. Formulas for the Same Plans

9. Barth Variable Sharing Plan—up to either low or high task
For beginners.
It gives a high wage for low production efficiencies without any guarantee.
Tables must be used.
This plan is not recommended above task.

10. Emerson Empiric Scale Plan—between 70% and 100% task only
For gradual transition from daywork plan to high piece-rate plan.
It avoids the abrupt step and may be justified in some cases.
The empiric principle is only used within the above limits, and outside of these, other plans are preferable.

11. Accelerating Premiums (Parabolic) Plans—most generous of all earning curves above high task
Complies with Fair Labor Standards Act without guaranteeing full time rate.
Can be made to pass any two efficiency-earning points and can meet one further condition.
A family of these curves can be suited to various needs in the same plant.
Recommended for supervisors.

FIG. 4a. Plans Which Are Justified, for What, Why, and How (*Cont'd*)

kinds of work it may not be sufficiently important. For instance, **repair jobs or small lot jobs** in a "job order" plant are of short duration and, if they recur at all, are likely to recur in varied form. Similarly, miscellaneous office duties, **drafting and indirect production jobs,** although not of so short a duration, may at least be irregular and therefore unpredictable as to time needed. **Extremely skilled work** such as toolmaking, automatic tool setting, die-cutting, pattern-making, pipefitting, electrical installation, etc., and **extremely unskilled work** such as sweeping, cleaning, etc., are often alike in the characteristic of uncertainty. In exceptional cases every one of these jobs has been put upon a task basis. Time rates are likely to prevail in this field, especially where companies are small. In either a small plant or a small department, an employee is known by name and reputation. This makes possible a "public opinion" which prevents him from taking undue advantage of time rates. This is the reason why time payment was **satisfactory for certain trades,** particularly in the time of trade guilds. It is the secret of managing salary groups today, such as clerks in banks. Time rates, since they have no automatic relation to productive efficiency, should be supported by **positive supervision and regular readjustment of rates.**

The calculation part of this plan is too simple to need actual illustration and the supervision part is too intangible to allow more than general statements. Frederick W. Taylor once said:

> The system by which the writer proposed managing the men who are on daywork consists in paying men and not positions. Each man's wages, as far as possible, are fixed according to the skill and energy with which he performs his work, and not according to the position which he fills. Every endeavor is made to stimulate each man's personal ambition. This involves

9. Earning = Sq. root of a prod. × Rt. per hr.
Up to 62½% or 100% of high task, $E = \sqrt{H_t H_a} \quad R_h$
From 100% of high task on, use another plan as No. 5.

10. Up to 66⅔% of high task (low task), $E = H_a R_h$, as in No. 1
Earning = Time wages × Unity plus an empirical B from table.
Between 66⅔% and 100% of high task, $E = H_a R_h \quad (1 + B)$
From 100% of high task on, use another plan as No. 3.

11. At all points, $E = BH_aR_h + \frac{(W - B)H_t^nR_h}{H_a^{(n-1)}}$

Where B = Guarantee rate, in percent of H_aR_h
W = Wages, in percent of H_aR_h, at task efficiency
$N = \frac{W}{W - B}$

FIG. 4b. Formulas for the Same Plans (*Cont'd*)

keeping systematic and careful records of the performance of each man, as to his punctuality, attendance, integrity, rapidity, skill, and accuracy, and a readjustment from time to time of the wages paid him, in accordance with this record.

The approved practice is to evaluate all jobs regardless of who may hold them, but Taylor's goal is also met by using merit rating for time-rate employees from which individual differentials are added to the impersonal base rates. Any of the other nonfinancial incentives may also be helpful. Supervisions must be more thoroughly applied to get extra productivity from time workers. Expectations as to results should not be great.

MEASURED DAYWORK.—Attempts have been made to put incentive into time wages through a mixture of job evaluation and merit rating. Each man-job is assigned an hourly rate which is composed of two sets of values. First part is based on: (1) skill, (2) responsibility, (3) mentality, (4) working conditions, (5) physical application, and others. This rate becomes the base rate and is little different from any well-evaluated job rate. Second part is based on employee-controlled factors such as: (1) quantity of production, (2) quality of production, (3) versatility, (4) dependability, and others. These factors are also evaluated and the combined value or weight is added to that already derived for base rate, raising it anywhere from one-sixth to one-third. Thus a job rating and a man rating are combined to give the "measured" day rate. An incentive is now brought to bear by means of periodic reviews of the employee-controlled values by which corrections in rates may be made either up or down.

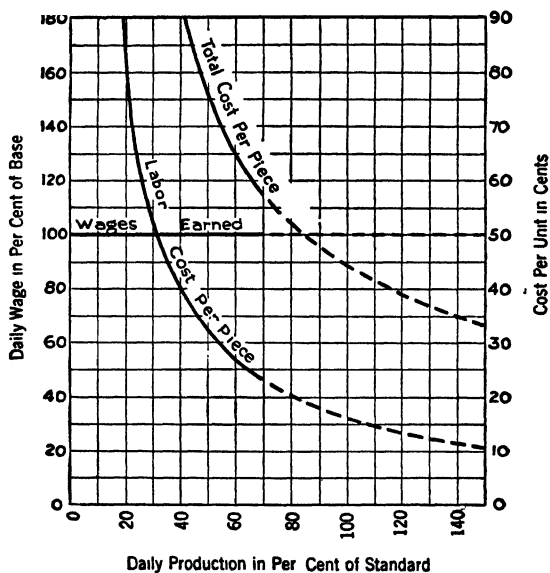



FIG. 5. Time or Day Rate Plan

Per Cent of Production H_s/H_a	Per Cent of Total to Base Wage for Full Day $E/H_a R_h$	Total Daily Wage in Dollars E	Number Pieces per Day	Time Saved per 8-Hr. Task in Hours $H_s - H_a$	Labor Cost per Piece in Dollars	Total Cost per Piece in Dollars
0	100	3.84	0	fictitious	3.84*	7.68*
10	100	3.84	2.4	− 72.0	1.60	3.32
20	100	3.84	4.8	− 32.0	.80	1.72
30	100	3.84	7.2	− 18.6	.53	1.18
40	100	3.84	9.6	− 12.0	.40	.92
50	100	3.84	12.0	− 8.0	.32	.76
60	100	3.84	14.4	− 5.3	.27	.66
66	100	3.84	16.0	− 4.0	.24	.60
73	100	3.84	17.5	− 3.0	.22	.56
80	100	3.84	19.2	− 2.0	.20	.52
89	100	3.84	21.4	− 1.0	.18	.48
100	100	3.84	24.0	0.	.16	.44
114	100	3.84	27.4	1.0	.14	.40
133	100	3.84	32.0	2.0	.12	.36
145	100	3.84	34.8	2.5	.11	.34

* Not per piece.

FIG. 6. Time or Day Rate Data

Period for rate revision is a month in case of beginners and 3 months in case of seasoned operatives. This involves recording, elapsed time, and other achievements per work assignment. Meticulous recording of such data should by itself act as a nonfinancial incentive, and has long been used by able foremen to prevent low efficiencies under time rates. Difficulty with Measured Day plan is that unnecessary complication has been introduced without getting the automatic response that comes from a true incentive. Furthermore, necessity of weighting such illusive factors as versatility, dependability, and others throws whole rate off a scientific foundation, and the periodic revision brings fear a little too ever-present. It would be as effective and much less annoying if the revisions were applied on the exception principle rather than periodically. Even then there would be the fear of subjective judging. **Two virtues of genuine incentive plans are wholly lacking:** automaticity and impersonality, while simplicity, main excuse for using time wages, is partially sacrificed.

DIFFERENTIAL TIME PLAN WITH BONUS STEP OR STEPS.—This plan was long called the Standard Time plan but a few years ago an entirely different plan usurped that name and through much publicity has come to be the better known under that designation. The plan may be expressed as follows:

Earning = Ordinary time wages up to high task
= 1.20% Ordinary time wages at and above task, or several steps

See Figs. 7 and 8.

The simplest way in which an ordinary time plan can be transformed into an extra-financial incentive plan is to use **two time rates,** one on each side of a task. In other words, establishment of a task and introduction of a second time rate are sufficient changes in the plan to change its main characteristics. Not only has the plan become related to production, but it has incorporated a strong inducement for the employee to produce at task. As in all plans using the time guarantee, the rate below task may be lower than the base if desired. As in all plans using the bonus step, this step may be small or large. If task is high, that is, the same as for most strong plans, then a single step should not be less than 20% relative to base wages. This gives an efficiency-earning point which has been widely successful and, if every other factor is normal, should hold response above task. It cannot be expected, however, to hold response much above task because there is no further possibility of automatically increased earnings. The plan is therefore suited to jobs where a **fixed amount of production** is desired, rather than where maximum response is desired. Up to this limit the single step plan is as strong as any other. It is simple to comprehend and simple to calculate.

Application of Differential Time Plan.—Wherever an ordinary time plan has preceded job standardization, it may be desirable to retain time rate up to task as a guarantee. For this reason and because this two-rate time plan introduces the least possible amount of newness, it is an easy plan to use in superseding ordinary time-rate plan. If in addition some of the job characteristics already cited as usually accompanying ordinary time plan still remain, then this two-rate time plan is likely to

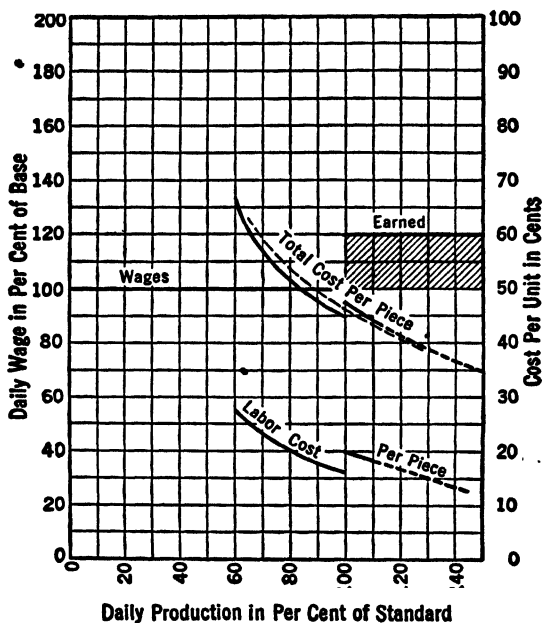



FIG. 7. Differential Time Plan, Two Rates

Per Cent of Production H_s/H_a	Per Cent of Total to Base Wage for Full Day $E/H_a R_h$	Total Daily Wage in Dollars E	Number Pieces per Day	Time Saved per 8-Hr. Task in Hours $H_s - H_a$	Labor Cost per Piece in Dollars	Total Cost per Piece in Dollars
60	100	3.84	14.4	− 5.3	.27	.66
66	100	3.84	16.0	− 4.0	.24	.60
73	100	3.84	17.5	− 3.0	.22	.56
80	100	3.84	19.2	− 2.0	.20	.52
89	100	3.84	21.4	− 1.0	.18	.48
100	120	4.61	24.0	0.	.19	.47
114	120	4.61	27.4	1.0	.17	.43
133	120	4.61	32.0	2.0	.14	.38
145	120	4.61	34.8	2.5	.13	.36

FIG. 8. Differential Time Data, Two Rates

fill requirements most suitably. It may be looked upon as doing automatically what any good supervisor would like to do with ordinary time wages, that is, raise and lower an individual's rate every time that individual raises and lowers his production efficiency. Because it is strong at task, and no stronger beyond task, this plan is also appropriate for **group or related individual jobs** in which cooperation for a reasonable production is more desired by management than competition for individual excellence. For instance, there are machines which carry a high overhead ratio making a certain capacity important, but if those machines are too delicate to warrant any overcapacity, it is equally important that the incentive should not incite beyond the optimum speed. In brief, the plan has as much strength at task as any of more complex plans and should probably be used more widely.

HIGH PIECE-RATE PLAN: DEFINITION.—

Earning = 1.30 Basic piece rate × Number of pieces
(In general, any fraction above unity.)

See Figs. 9 and 10.

While either an excessively high or an excessively low piece rate is unwise, there is nothing against the basic piece rate (see first part of Fig. 11 and Fig. 12), that is, the one passing through the 100% efficiency and the 100% base rate points. On the other hand, it is usually conceded that any operative who performs at 100% of high task should be paid at least 120% of base wages or vice versa, that is, at least 120% base wages must be offered to induce 100% efficiency. The particular plan here charted is 1.30 piece rate and intersects the base wage line at 75% efficiency. This is a practical place to start any strong incentive for performance better than ordinary time work. The old-fashioned piece rate, that is, piece rate as used before there were carefully derived tasks, usually started with a very high slope, went through a series of cuts, and ended with a very low slope. Taylor deliberately retained such a low slope or rate as a punitive force against less than task performance. It allowed him to insert a large step bonus, usually 50%, at high task after which he gave virtually a high piece rate of 1.25%. The punitive rate always gave trouble, and was eliminated by his associates, Henry L. Gantt and Dwight V. Merrick.

Piece rate may be looked upon as the **limit of multiple time rates,** that is, an infinite number of infinitesimal and equal advances in both rate and efficiency. The slope can vary with a nominal task as already indicated but all piece rates either do, or would if extended, pass through the origin on the chart. When they are used to the origin, they are called straight piece rates. When only portion above some designated time line is used, the plan is called piece rate with time guarantee or the Manchester plan. Use of a guarantee formerly depended on nature of work or on history of work-group. Under the Fair Labor Standards Act, a minimum earning has become mandatory but in most skilled work this minimum is rarely invoked.

When managerial control is inadequate or, if adequate, when there is an emergency, a guarantee has always been necessary. When beginners are being trained, a **guarantee** is necessary.

In the case of employees who have heretofore been on the day rate

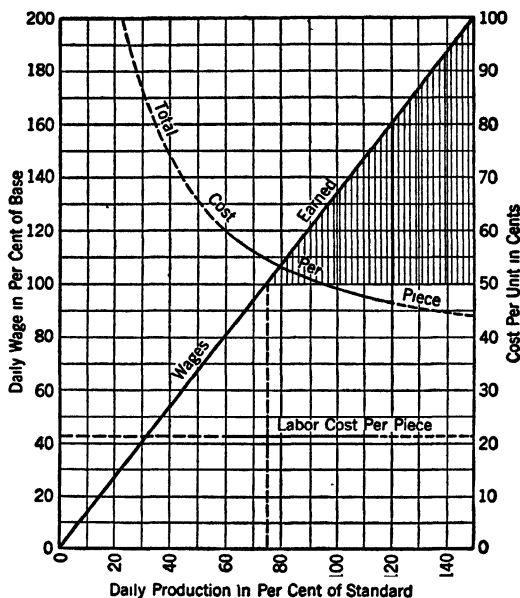



FIG. 9. High Straight Piece-Rate Plan

Per Cent of Production H_s/H_a	Per Cent of Total to Base Wage for Full Day $E/H_a\,R_h$	Total Daily Wage in Dollars E	Number Pieces per Day	Time Saved per 8-Hr. Task in Hours $H_s - H_a$	Labor Cost per Piece in Dollars	Total Cost per Piece in Dollars
0	0	0	0	fictitious	0*	3.84*
10	13	.50	2.4	− 72.0	.21	1.93
20	26	1.01	4.8	− 32.0	.21	1.13
30	39	1.51	7.2	− 18.6	.21	.86
40	53	2.02	9.6	− 12.0	.21	.73
50	66	2.52	12.0	− 8.0	.21	.65
60	79	3.02	14.4	− 5.3	.21	.60
66	87	3.36	16.0	− 4.0	.21	.57
73	96	3.68	17.5	− 3.0	.21	.55
80	105	4.04	19.2	− 2.0	.21	.53
89	117	4.49	21.4	− 1.0	.21	.51
100	131	5.04	24.0	0.	.21	.49
114	150	5.76	27.4	1.0	.21	.47
133	176	6.72	32.0	2.0	.21	.45
145	190	7.31	34.8	2.5	.21	.44

* Not per piece.

FIG. 10. High Straight Piece-Rate Data

basis, these rates have often been retained as guarantees when an extra-financial incentive plan is installed. This practice is not always necessary, however, and if unnecessary it should not be done. If the guaranteed rate is lower than base rate level, it will act automatically to keep the employee out of its reach but there are other difficulties in the way of such rates. If the guarantee is at base level, as is customary, then precautions must be taken to prevent less ambitious employees from remaining on it indefinitely. All remuneration along a high guarantee line is costly to the company and should be looked upon as a penalty to deficient management.

Although **straight piece rate** is established in relation to a task, the plan does not of itself indicate where the task is. From direct proportion between production and earnings employees know at all times what to expect, but the employer does not know what to expect beyond a constant labor cost per piece. In other words, employees can adopt their own concepts of task. These concepts vary with different employees. It is evident that a company standard for task should always be kept in sight and, when feasible, individual production records should be used as a nonfinancial incentive. Considerations of overhead are too important to allow full freedom in the case of employees who are easily content. With no guarantee this trouble manifests itself more in turnover than in shirking. In fact, a high piece rate makes a strong appeal to ambitious employees and average response is certain to be fairly high, provided management does not cut rates and utilizes proper control of conditions. Piece rate when correctly handled is fair as a wage, strong as an incentive, and simple to operate. Management is more likely than labor to shun piece rate. Certainly management must do a good job if piece rate is to be effective.

Objection is on two characteristics, one real and one imaginary: (1) It is thought that **piece rate stimulates individual starring** to the detriment of cooperation. This belief is well founded and if cooperation is more important than individual starring, as is coming to be the case in many plants, piece rates or any other strong incentive based solely on quantity should not be used on individual application but on a group application. (2) It is thought that rates per piece make it **impossible to reward virtues** such as versatility, loyalty, and length of service. This condition is true only when rates are in terms of pieces and can be entirely obviated by expressing rates in terms of standard hours, that is, by establishing rate on the number of pieces which have been standardized as an hour's task. This "standard hour" plan is not thereby changed in its earning curve from piece rate. The change is in administration only. Since this rate is related to time, it is possible to vary it for different employees without varying the number of pieces to standard hour. On the other hand, piece rate, in several forms, is more used than all other plans combined.

Application of High Piece-Rate Plan.—Since piece rates can be applied with or without guarantees, with or without step bonuses, and expressed in either pieces or standard hours, it is evident that piece rates can be suited to many different sets of conditions. Even the difficulty of counting large quantities of product, that is, for short cycles of work, may be surmounted by volumetric measure or by use of counting scales, etc. In 1940 about 37% of factory employees, or 59% of those on

extra-financial incentives, were on some form of piece rate (see Fig. 1). The most fundamental conditions for this type of incentive are **independent operations and steadiness of operation,** that is, a major operation entirely completed by one operator and repeated by him for days at a time. The next likely condition is **absence of expensive equipment,** but this condition holds only where there is no step bonus in the plan which can be relied upon to maintain response at a high point of efficiency. With a generous step bonus at high task, piece rate is the best plan for **individual work involving expensive equipment.** No piece-rate plan without a time guarantee is suitable for beginners. Neither is a piece-rate plan suitable for low or inaccurate tasks. A low task throws a steep-slope earning curve into excessively high earnings at all points of production efficiency. To avoid this possibility tasks must be accurately set and rates equalized as between various jobs in the same class of work. In all cases the supply of work must be guaranteed.

Example of High Piece-Rate Plan.—Lycoming Manufacturing Co. used a high piece-rate plan where an earlier installation of piece rates had been unsatisfactory. Rigid inspection was set up to control quality. Comparing results before and after the installation of correct standards, the management stated that "the shortcomings came from the method of application rather than from fallacies in the plan itself."

1. Formerly the setting of piece rates seemed of minor importance as compared to other duties of the foreman, so that rates were established in a haphazard fashion, in many instances by asking an operator how many he could produce.
2. Partiality was shown at times.
3. Rates many times were not adjusted in accordance with change of tools, method, and engineering design.
4. As no time study record was made, in case of dispute there was no means of showing how standard performance was accomplished.
5. Rates were reduced or increased at random.
6. No definite schedule of base rates with ratio of incentive to hourly hiring rates existed.
7. Little coordination was possible between manufacturing and inspection, engineering, tool design, and accounting.
8. No standard or check of the ratio of daywork hours, both direct and indirect, to piece-rate hours was available.

It is claimed in many cases that the **straight piece-rate plan is more satisfactory** than other plans for the reasons that it requires less clerical help in the accounting department to keep it operative and that it abolishes the feeling among the direct labor personnel that they are being paid under a plan which to them is not fully understandable and under which they are not certain but that they may be cheated on pay day.

MERRICK DIFFERENTIAL PIECE-RATE PLAN: DEFINITION.—

Earning = Basic piece rate up to 83% of high task
= 1.10% Basic piece rate between 83% and 100% of high task
= 1.20% Basic piece rate at and above high task

See Figs. 11 and 12.

In Taylor's writings the possibility of using more than one step bonus with piece rates is mentioned, but Taylor seems to have suggested such

extra bonuses for use beyond task, in fact, his whole thought was for "highclass" employees. He hoped through selection and training to develop employees who would work at or above task all of the time, and he saw no reason why the negative incentive of a low piece rate below task should not be used to reinforce the positive incentive for such performance at task. Merrick believed such a plan was too severe. He therefore proposed to remove the punitive rate and in its place to provide **two piece rates, one basic, the other between basic and high.** Merrick saw that this would not only eliminate a discouraging feature but would add an encouraging feature for those employees who, although not high producers, might become such. Elimination of the punitive piece rate and division of the remaining step sacrifices some of the strength which the Taylor plan has at task, but the final piece rate at and above task is 1.20 in slope compared with the 1.25 slope of the Taylor high piece rate at and above task. Although this difference is slight, and could be eliminated, the Merrick plan is more commendable for its **strength through intermediate range of efficiencies** than for its strength at and above task. It permits earning of a sudden increment at moderate efficiency, namely, 83%, and then offers a repetition of the experience at high efficiency, namely, 100%. Its **psychology is excellent.** A bonus at 83% efficiency will seem possible of accomplishment to a partially trained or imperfectly skilled operator and, unless it is ridiculously small, he will try to win it. When he has once achieved this success, he will never be satisfied without it. Furthermore, he will have gained confidence for further efforts and after a brief period of contentment will resume the climb for the second reward. The trouble with a single step at high task is that some employees will not attempt it. Merrick made his two steps equal in per cent, 10%, but it is better to divide the 20% into unequal steps such as 8% and 12%. In no case attempt a step at anything less than task without the second step at task, because operators already high in efficiency may be content to take their former earning at a lower efficiency.

Application of Merrick Plan.—This plan is effective for high productions but is particularly suitable for the intermediate ranges of efficiency. For this reason it is a **splendid upgrading plan** for operators formerly on the straight basic piece-rate plan. It could also be used, in part, as a transition from a time rate to high piece rate, in which case the intermediate rate would cut the corner much as empiric plans do, but in a simpler manner. It is flexible in that it automatically stimulates all degrees of skill. Like single straight piece rates, it is hardly practical for the job order type of work or for uncontrolled management, but it would be practical for conditions which are controlled as far as management is concerned, but still subject to some variation on the part of operators.

Tables should be prepared for payroll computation. When such tables are used clerical work is not materially more than for straight piece rate. Some pains must also be taken at the time of installation to illustrate earnings at critical points of efficiency.

Example of Merrick Plan.—Atlas Underwear Co., makers of knit goods, installed the Merrick plan for all finishing room operators to replace a straight piece-rate plan which had never had correct tasks.

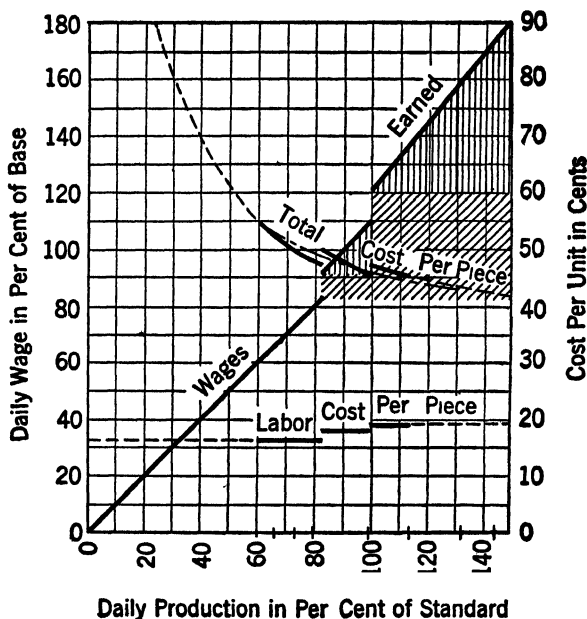



FIG. 11. Merrick Differential Piece-Rate Plan

Per Cent of Production H_s/H_a	Per Cent of Total to Base Wage for Full Day E/H_aR_h	Total Daily Wage in Dollars E	Number Pieces per Day	Time Saved per 8-Hr. Task in Hours $H_s - H_a$	Labor Cost per Piece in Dollars	Total Cost per Piece in Dollars
0	0	0	0	fictitious	0*	3.84*
10	10	.38	2.4	−72.0	.16	1.88
20	20	.76	4.8	−32.0	.16	1.08
30	30	1.15	7.2	−18.6	.16	.81
40	40	1 54	9.6	−12.0	.16	.68
50	50	1 92	12.0	− 8.0	.16	.60
60	60	2.30	14.4	− 5.3	.16	.55
66	66	2 56	16.0	− 4.0	.16	.52
73	73	2 80	17.5	− 3.0	.16	.50
80	80	3.07	19.2	− 2 0	.16	.48
89	98	3.76	21.4	− 1.0	.18	.48
100	120	4.61	24 0	0	.19	.47
114	137	5.26	27.4	1.0	.19	.45
133	160	6.14	32 0	2.0	.19	.43
145	174	6.67	34.8	2.5	.19	.42

* Not per piece.

FIG. 12. Merrick Differential Piece-Rate Data

A 40% average increase in production and a material reduction in total cost per unit resulted. Most of the employees were women, many of whom had been content with low efficiencies. Individual production records were kept and shown daily during the installation. Two girls did all the payroll work.

GANTT TASK AND BONUS PLAN: DEFINITION.—

Earning = Time wages up to 100% of high task
= 1.20 Basic piece rate at and above high task

See Figs. 13 and 14.

This plan is a **combination of time rate and high piece rate** with a 20% step bonus between them. The transition is at high task. Thus, strong incentive at task and steep slope thereafter make this plan practically as strong as the Taylor plan. Time rate below task removes fear and makes the plan more charitable. Gantt did not intend, however, to give charity to low producers. He provided bonuses for foreman based on the number of his men who made task and further bonuses based on all of his men making task. This procedure put a strong emphasis on both training and general foremanship. Furthermore, the time rate was usually set below base. This feature, although desirable on cost and incentive considerations, makes the hiring of workers difficult and it is not generally used during prosperous times. Gantt also thought it important that **piece rate be figured in terms of standard hours** rather than in terms of pieces. He claimed that this transferred employee thinking from dollars to the amount of work. The real reason for standard hours, however, is the flexibility which is made possible. Not only can rates be varied for individual employees but bonus step can be varied for individual jobs. Gantt found that 10% to 15% was sufficient for **machine tending.** At same time he used 30% to 40% for **machine tool operations** and certain **textile operations** involving attention or eye strain.

Application of Gantt Plan.—There is perhaps no better plan than the Gantt plan for employees who operate expensive machinery. The single large step makes it worth while for all who can to make task and the steep slope beyond task encourages many to exceed this production. This situation favors the approach to full machine capacity and keeps distribution of machine rates at a minimum per unit of product. At the same time the operator is protected against loss of all wage if the machine should break down. As in all plans which retain the time guarantee, some care must be taken to prevent unnecessary inefficiency. This can be done by supervision but, in general, the plan should not be applied to low-grade or untrained operators. The Gantt plan may be installed to follow **either time wages or straight piece wages.** In the former case it is necessary at first to support the plan with training and close supervision. In either case individual production records should be kept until habits of task making have become well fixed. Like most of the early plans, this one has been modified in practice almost beyond recognition. The so-called "standard time" plans of the Westinghouse Electric & Manufacturing Co. and the Dennison Manufacturing Co. represent modifications which have taken another name. The plan of Cheney Brothers was even more modified without taking another name.

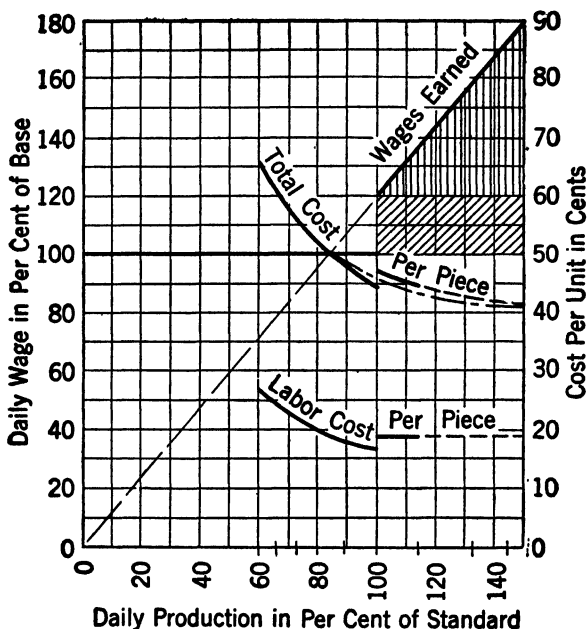



FIG. 13. Gantt Task and Bonus Plan

Per Cent of Production H_s/H_a	Per Cent of Total to Base Wage for Full Day $E/H_a R_h$	Total Daily Wage in Dollars E	Number Pieces per Day	Time Saved per 8-Hr. Task in Hours $H_s - H_a$	Labor Cost per Piece in Dollars	Total Cost per Piece in Dollars
60	100	3.84	14.4	− 5.3	.27	.66
66	100	3.84	16.0	− 4.0	.24	.60
73	100	3.84	17.5	− 3.0	.22	.56
80	100	3.84	19.2	− 2.0	.20	.52
89	100	3.84	21.4	− 1.0	.18	.48
100	120	4.61	24.0	0.	.19	.47
114	137	5.26	27.4	1.0	.19	.45
133	160	6.14	32.0	2.0	.19	.43
145	174	6.68	34.8	2.5	.19	.42

FIG. 14. Gantt Task and Bonus Data

Example of Gantt Plan.—Sayles Finishing Plants, Inc. installed a Gantt plan based on careful job standardization. Efficiencies as high as 130% of task, and wages as high as 60% above base resulted. The management cited that the plan (a) guaranteed base wage for those who failed to make task, (b) gave full earnings above task, (c) simplified management, (d) reduced total factory cost per unit, (e) increased production.

HALSEY (50-50) CONSTANT SHARING PLAN WITH TIME GUARANTEE: DEFINITION.—

Earning = Time wages up to 62½% of high task (low task)
Earning at and above low task = Time wages plus half wages saved relative to low task

See Figs. 15 and 16.

A piece-rate earning curve passing time wages at low task gives an excessively high wage for efficiency points thereafter. A constant sharing earning curve passing time wages at high task gives an excessively low wage thereafter. Appreciation of these facts is necessary to realize that a **constant sharing earning curve,** if properly designed to pass time wages at low task, will give an adequate incentive for certain efficiency points. The range through which a (50–50) constant sharing plan accomplishes this result is between low task, 62½% of **high task,** and 90% of high task. At the latter efficiency the earning curve intersects that of high piece rate and then diverges below it. The (50–50) constant sharing plan, originally called the Halsey Premium plan, is usually described as designed for work not "time studied." Historically that is correct but it is equally true that the plan is suited to all tasks which are estimated, roughly timed or well standardized in themselves but uncertain in accomplishment from external deficiencies. In any of these cases it is desirable to have an early but slow rise in earning or, in other words, an earning curve increasing above time rate but without varying as greatly in proportion as performance varies. There are many applications of the plan today in which the jobs are well studied, but, on account of certain uncontrolled variables, task is deliberately set around 62½% efficiency instead of at 100% efficiency.

Application of Halsey (50-50) Plan.—The plan should be applied only to work which for any reason is uncertain in possibilities. For all such work it provides a safe and, at the same time, a generous incentive through the intermediate range of efficiencies. It cannot be expected to draw average response beyond 90% of high task, although it might do so in cases where high piece rate had never been experienced. For these reasons the (50–50) sharing is usually restricted to the **jobbing** type of work, **maintenance,** etc., and to employees **formerly on ordinary time wages.** Although (50–50) division of wages saved carries an aspect of fair play, that division alone does not determine justice. Nearly all divisions or sharings are in use and many of them are fair for the particular task location and particular nature of the situation. Westinghouse Electric & Manufacturing Co. has used numerous proportions down to (10–90), the latter proving fair for stockroom clerks who can double performance by 10% increase in effort. If work can be well

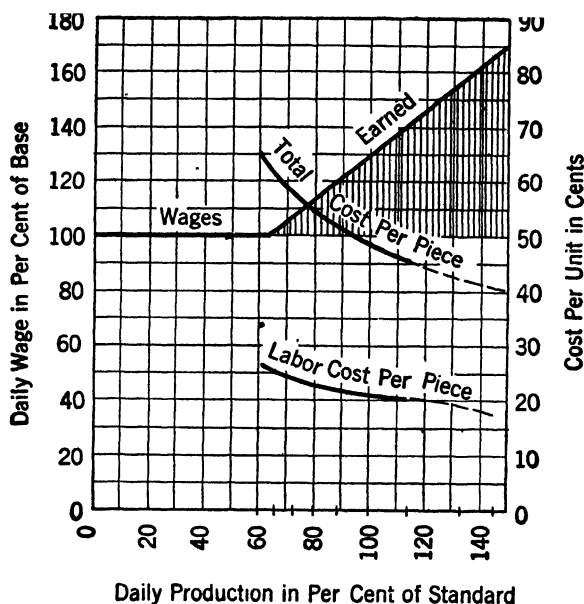



FIG. 15. Halsey (50–50) Constant Sharing Plan

Per Cent of Production H_s/H_a	Per Cent of Total to Base Wage for Full Day $E/H_a R_h$	Total Daily Wage in Dollars E	Number Pieces per Day	Time Saved per 8-Hr. Task in Hours $H_s - H_a$	Labor Cost per Piece in Dollars	Total Cost per Piece in Dollars
60 (96)*	100	3.84	14.4	− 5.3 (− 0.33)*	.27	.66
66 (107)	103	3.98	16.0	− 4.0 (0.50)	.25	.61
73 (116)	109	4.17	17.5	− 3.0 (1.125)	.24	.58
80 (128)	114	4.38	19.2	− 2.0 (1.75)	.23	.55
89 (143)	121	4.66	21.4	− 1.0 (2.375)	.22	.52
100 (160)	130	5.00	24.0	0. (3.00)	.21	.49
114 (183)	142	5.42	27.4	1.0 (3.625)	.20	.46
133 (213)	156	6.00	32.0	2.0 (4.25)	.19	.43
145 (232)	166	6.38	34.8	2.5 (4.55)	.18	.41

* A secondary efficiency scale is made necessary for each of the values in these columns by the use of (100) for low task.

FIG. 16. Halsey (50–50) Constant Sharing Plan

standardized and controlled, stronger plans are more effective and less costly in clerical work.

Example of Halsey (50-50) Plan.—General Iron Works installed a plan well interwoven with production control. Earned premiums, that is, amount above day wages, was not paid until after 2 weeks. Individual production records were kept, and more energetic men were promoted; some eventually became foremen. Less energetic men who failed to make their tasks were obliged to fill out excess labor tickets stating reasons for the failures.

Of the company's 50% share, one-tenth went to the foremen who were thereby stimulated to do all they could to increase departmental efficiency. The management claimed that typical efficiency relative to high task rose to around 85%, and earnings 20% above hourly rate. Low task was set by a time study staff known as the estimating department.

(40-60) CONSTANT SHARING PLAN AS SUBSTITUTE FOR TIME GUARANTEE: DEFINITION.—This plan is like the previous Halsey plan except "half" is replaced with 40%. But since this straight line of earning is to end at 70% efficiency and time wages, rather than at either task point, it is necessary to redefine it as a working formula:

Earning = 14 × Hours standard + 21 × Hours actual, all multiplied by 1/35 of the rate per hour
(This curve plotted has a vertical intercept of 3/5 and a slope of 2/7)
See Figs. 17 and 18.

Here the employee's share of wages saved is reduced to 40%, and sharing is extended back from 70% efficiency and time wages, to zero efficiency. This means that a beginner will earn at least 60% base time wages and will be encouraged to ascend in earning along a gradually sloped straight line until 70% of high task is achieved. Through low efficiencies the plan is a compromise between the charity of time wages and the severity of piece wages. Under the Fair Labor Standards Act this device is needed for many of the less-skilled jobs. Despite the curious form of the working formula it is simple to calculate and easily understandable in the general formula which can be used if corrections are made for task. The earning curve connects two logical points, that of no performance with cheap hiring, and that of **intermediate performance with full-time wages.** Characteristics resulting from these conditions are obvious. Such a curve came into use for beginners (see Bigelow-Knoeppel plan in Lytle's Wage Incentive Methods) because Bigelow found that it about averaged the "effort line," a reverse curve representing the time-efficiency progress of learners (see Fig. 28).

Application of (40-60) Sharing Plan.—This plan is **suitable for almost any beginner of skilled work,** that is, work which takes at least one month to learn, or it can be used for older employees who have been content with an unearned time guarantee. In the former case this plan should automatically reduce the time for acquiring intermediate efficiency, and in the latter case it should automatically prevent undue content with less than intermediate performance. Beyond 70% of high task two high time rates, a high piece rate or a (50–50) constant sharing

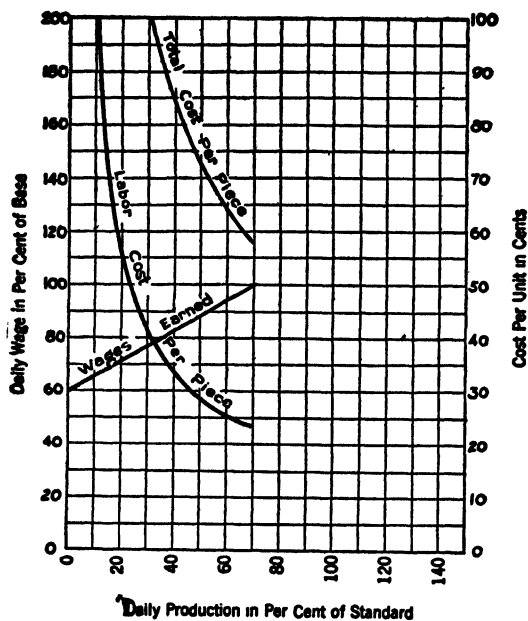



FIG. 17. (40–60) Constant Sharing Plan As Substitute for Time Guarantee

Per Cent of Production H_s/H_a	Per Cent of Total to Base Wage for Full Day E/H_aR_h	Total Daily Wage in Dollars E	Number Pieces per Day	Time Saved per 8-Hr. Task in Hours $H_s - H_a$	Labor Cost per Piece in Dollars	Total Cost per Piece in Dollars
0	60	2.30	0	fictitious	2.30*	6.14*
10	66	2.53	2.4	−72.0	1.05	2.77
20	71	2.74	4.8	−32.0	.57	1.49
30	77	2.97	7.2	−18.6	.41	1.06
40	83	3 18	9.6	−12.0	.33	.85
50	89	3.39	12.0	− 8 0	.28	.72
60	94	3.62	14.4	− 5.3	.25	.64
66	97	3.73	16.0	− 4 0	.23	.59
70	100	3.84	16.8	− 3.4	.23	.59

* Not per piece.

FIG. 18. (40–60) Constant Sharing Data

plan may be used. The time rates should be approached by means of a small step bonus at 70% of high task and a second larger one at 100% of high task. The high piece rate should be approached through an empiric curve such as Emerson's, described later. The (50–50) constant sharing should be approached by a single small step bonus at 70% of high task. Choice of these plans depends on conditions described under their names.

Example of (40-60) Sharing Plan.—Some time ago, a textile plant applied this plan to beginners. Time of training was at once reduced from 6 months to 10 weeks in case of hosiery loopers, and average proportion of beginners finally attaining grade of experienced operators was raised and maintained from 1 out of 5, to 3 out of 4 on this particular operation. This salvage of potential operators was in itself sufficiently gratifying to justify the plan. Number of beginners ranged between 60 and 100, out of a total payroll of 1,200, and clerical work was accomplished by one woman, who was a college graduate with executive experience and did much more than the routine. Personal influence is particularly important where young girls are involved.

ORIGINAL BEDAUX POINT PLAN.—The original plan is like Fig. 15 except that the "half" is replaced with 75% and the task is high (see Figs. 19 and 20). Distinctiveness of this plan is not its earning curve but its **system of control.** In fact, full piece-rate earning was always used in a few installations, most notably that of B. F. Goodrich Co. Since the middle of 1941 the Bedaux engineers have been using the full sharing in all new installations (see High Piece-Rate Plan). As formerly installed, the three-fourths sharing from high task point is weak, but the remaining one-fourth sharing applied as bonus to indirect producers, foremen, etc., and the control, operated to expedite all movements of goods in process, compensate enough to get results. Control is brought about by establishing a **man-minute** called the Bedaux or "B." This is defined as:

> A fraction of a minute of effort plus a fraction of a minute of compensating relaxation, always aggregating unity but varying in proportion to nature of the strain.

Letting lambda (λ) equal the coefficient of rest, this quantity plus unity is multiplied with any dominant time (T_d) from a time study to derive time allowed (H_s):

$$(1 + \lambda)\ T_d = H_s, \text{ and } \frac{60}{1 + \lambda} = H_s$$

The factor 60 comes from the assumption of 60 B's per minute as standard, a high task but somewhat below that of Taylor. Restoring rest allowed, $\lambda H_s = 60 - \dfrac{60}{1 + \lambda}$. Working part of a B, $(1 - \lambda)\ H_s$, varies from 1/3 to 9/10 and is kept secret by Bedaux engineers (see Paul Audibert, General Consideration Upon the Rational Organization of Labor in Mines, Société de Pontusola). All jobs, including indirect production work, etc., are standardized in B's and reports are made periodically in which the actual B's are compared with standard B's. Fundamentally the same thing is possible for man-hour units, especially if they are

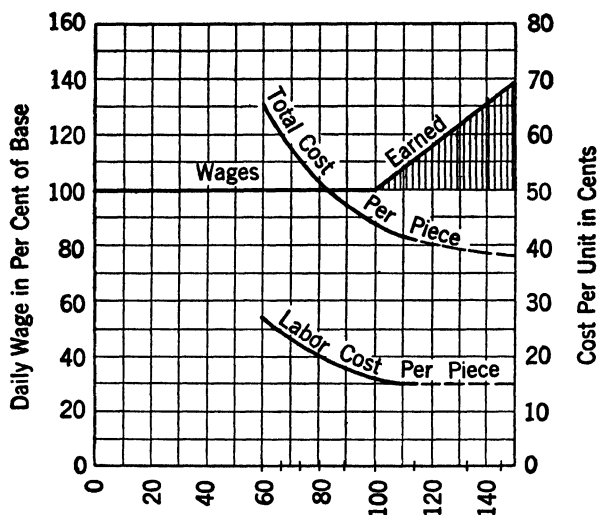



FIG. 19. Original Bedaux Point Plan—a (75–25) Constant Sharing Through High Task

Per Cent of Production H_s/H_a	Per Cent of Total to Base Wage for Full Day $E/H_a R_h$	Total Daily Wage in Dollars E	Number Pieces per Day	Time Saved per 8-Hr. Task in Hours $H_s - H_a$	Labor Cost per Piece in Dollars	Total Cost per Piece in Dollars
60	100	3.84	14.4	− 5.3	.27	.66
66	100	3.84	16.0	− 4.0	.24	.60
73	100	3.84	17.5	− 3.0	.22	.56
80	100	3.84	19.2	− 2.0	.20	.52
89	100	3.84	21.4	− 1.0	.18	.48
100	100	3.84	24.0	0.	.16	.44
114	111	4.25	27.4	1.0	.16	.41
133	125	4.80	32.0	2.0	.15	.39
145	134	5.15	34.8	2.5	.15	.38

FIG. 20. Original Bedaux "Point" Data

expressed decimally, but the fact is that no one before Bedaux, excepting Gantt, ever set up such a system sufficiently well to make a complete whole, and Gantt did not insist on his various measures as a composite system. Since most incentive failures have been due to the **lack of managerial support,** this achievement of Bedaux is valuable and has received extensive endorsement. The real weakness of the plan is that haste in setting up control may result in superficial job improvement. In the past Bedaux engineers made little attempt to introduce fixtures or other major methods improvements. On the other hand, many companies were weak in production control. For such companies this plan was often suitable, particularly if they had already developed high-class job methods.

But Bedaux's more superficial time study involved an equally superficial man-rating, for the doubtful use of "leveling" time standards. In textile plants reduced labor costs were sought through additional machines assigned per operator which, without preceding waste elimination, amounted to rate cutting. Organized labor called it the "stretch-out" and rebelled (see Am. Federationist, vol. 42, and newspaper publicity of 1937).

Application of Original Bedaux Plan.—Within the conditions cited above, the Bedaux type of plan is most suitable for large companies. The extra clerical work required might not pay in a small company or, conversely, there is greater need of elaborate control in a large company. While the plan has made good in plants having a great amount of skilled handwork, it is most suitable for plants having either **highly developed machine operations,** i.e., already refined, or for plants **lacking entirely jig and fixture possibilities.** Because the Bedaux plan sets up standards for indirect production, the plan may be helpful wherever the proportion of that work to direct production is unusually high. It is used by some large corporations to facilitate interplant comparisons. Such companies have competent engineers, hence faults of installation have been avoided.

Example of Bedaux Plan.—Gillette Safety Razor Co. applied the plan and gained advantages: decreased costs; 25% to 30% increased earnings for employees; simplified control of nonproductive as well as productive labor. (For a complete example including filled-out forms see Lytle's Wage Incentive Methods.)

BARTH VARIABLE SHARING PLAN: DEFINITION.—

Earning = Rate per hour × The square root of the product (Hours standard × Hours actual)

See Figs. 21 and 22.

This plan, an improvement of the Rowan plan, was **intended for low task** and for **all efficiency points.** Its merit lies, however, in the portion below task and this is little affected by relocating it to high task. No other plan is so fair to both beginner and to employer regardless of task location. It is therefore presented in both locations. It avoids entirely employer risk at extremely low efficiencies and, provided the work is not difficult to learn, allows a good earning within a short time. In fact, it offers a much stronger incentive to rapid progress in learning than does the (40–60) constant sharing plan and does this without the

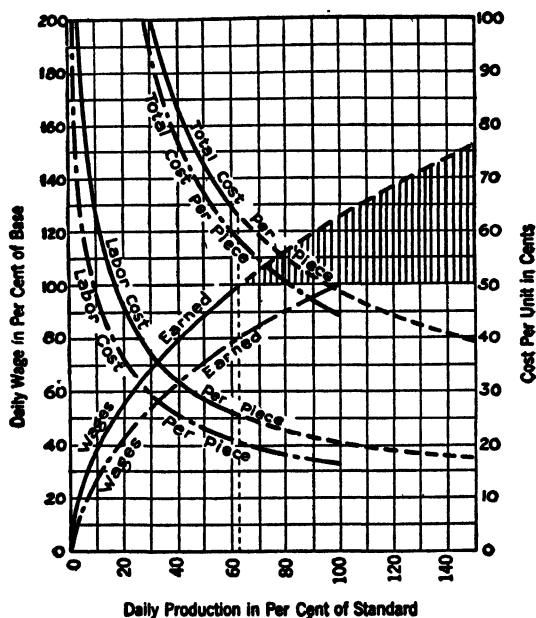



FIG. 21. Barth Variable Sharing Plan for Low and High Tasks

Per Cent of Production H_s/H_a		Per Cent of Total to Base Wages for Full Day E/H_aR_h		Total Daily Wage in Dollars E		Number Pieces per Day	Time Saved per 8-Hr. Task in Hours $H_s - H_a$		Labor Cost per Piece in Dollars		Total Cost per Piece in Dollars	
High†	Low†	High	Low	High	Low		High	Low	High	Low	High	Low
0	0	fictit	ious	0	0	0	fictit	ious	0*	0*	3.84*	3.84*
10	16	.32	.40	1.21	1.54	2.4	−72.0	−42.00	.50	.64	2.22	2.36
20	32	.45	.57	1.72	2.18	4.8	−32.0	−17.00	.36	.45	1.28	1.37
30	48	.55	.69	2.10	2.66	7.2	−18.6	− 8.67	.29	.37	.94	1.02
40	64	.63	.80	2.43	3.07	9.6	−12.0	− 4.50	.25	.32	.77	.84
50	80	.71	.89	2.71	3.44	12.0	− 8 0	− 2.00	.23	.28	.67	.72
60	96	.78	.98	2.97	3.76	14.4	− 5 3	− .33	.21	.26	.60	.65
66	107	.81	1.04	3.10	3.98	16.0	− 4 0	.50	.19	.25	.55	.61
73	116	.85	1.08	3.27	4.16	17.5	− 3.0	1.25	.19	.24	.53	.58
80	128	.89	1.13	3.41	4.35	19.2	− 2.0	1.75	.18	.23	.50	.55
89	143	.94	1.20	3.62	4.61	21.4	− 1.0	2.37	.17	.21	.47	.51
100	160	1.00	1.26	3.84	4.86	24.0	0	3.00	.16	.20	.44	.48
114	183	‡	1.34	‡	5.14	27.4	‡	3.62	‡	.19		.45
133	213	‡	1.42	‡	5.59	32.0	‡	4 25	‡	.18		.42
145	232	‡	1.52	‡	5.84	34.8	‡	4.55	‡	.17		.40

† High and Low refer to two different task locations, 100% and 62½% respectively.
‡ Omitted because they should not be used. * Not per piece.

FIG. 22. Barth Variable Sharing Data

extreme discouragement characteristic of piece rate. Its disadvantages lie only in its obscure definition and in its severity relative to time rates. Despite appearances, the formula is simple to figure and can be explained by tables. If it should be used to replace time payments, the introduction should be made most carefully.

The extreme left portion of earning curve would need to be replaced with a time rate to meet the provisions of the Fair Labor Standards Act, but only for such low efficiency points that the substitution would rarely come into use, that is, discharge would be well justified if such low efficiencies were recurrent.

Application of Barth Plan.—The plan is best suited to replace piece rates for beginners doing unskilled work which can be learned quickly. If the task is inaccurate, little danger is incurred to either party. On the other hand, if control is uncertain, so that beginner might be prevented from doing his best, the (40–60) constant sharing plan is more charitable. The Barth plan should not be used above task although it was originally meant to be so used. In either position it amounts roughly to (40–60) sharing above task and that is not effective for higher efficiencies even when located on a low task.

EMERSON EMPIRIC PLAN: DEFINITION.—

Earning = Time wages × The binomial $(1 + B_o)$
in which B_o is the empiric bonus as per Fig. 25.

See Figs. 23, 24, and 25.

In its entirety this plan comprises **time wages** to **66⅔% high task,** empiric bonuses from there to high task, ending at 120% time wages, and thereafter a **straight-line earning** which is 20% above and parallel to basic piece rate. Only the empiric portion of the plan is presented here because this is the distinctive portion which can be used with plans other than time rate on the low efficiency side and with high piece rate on the high efficiency side. The latter feature constitutes the Wennerlund plan developed and used in General Motors plants and is a much better termination. The object of empiric points is to locate points of efficiency-earning wherever desired regardless of any mathematical expression. It allows any desired path through intermediate efficiencies but the original path and all of its modifications are approximately arcs of circles concave upwards. Such paths give a gradual incentive and are claimed to be less exasperating to the **struggling type of operator.** There is no doubt of this claim but ease of mind is gained at expense of any step bonus and this means a weaker incentive with consequent scattering of individual responses.

It seems that Emerson's philosophy of incentives was quite contrary to that of Taylor and his followers. If a moderate, coaxing sort of incentive is preferred to a clean-cut yes-or-no type of incentive, then this plan is a correct transition through intermediate efficiencies. In fact, it is strange that Emerson did not carry the development beyond high task where it is most needed. This has since been done by the Accelerating plan.

Application of Emerson Plan.—The Emerson series of empiric points is suitable to connect any of the three beginner's plans with high piece rate. Kind of work has little bearing on the matter. The real issue is

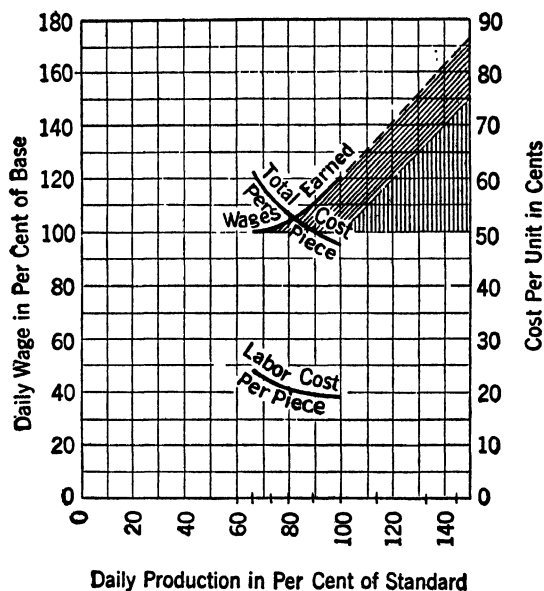



FIG. 23. Emerson Efficiency-Bonus Plan

Per Cent of Production H_s/H_a	Per Cent of Total to Base Wage for Full Day E/H_aR_h	Total Daily Wage in Dollars E	Number Pieces per Day	Time Saved per 8-Hr. Task in Hours $H_s - H_a$	Labor Cost per Piece in Dollars	Total Cost per Piece in Dollars
66	100	3.84	16.0	− 4.0	.24	.60
73	101	3 88	17.5	− 3.0	.22	.56
80	104	4.00	19.2	− 2 0	.21	.53
89	110	4.23	21.4	− 1.0	.20	.50
100	120	4.61	24.0	0	.19	.47

FIG. 24. Emerson Efficiency-Bonus Data

Efficiency in Per Cent of High Task	Bonus in Per Cent of Base Wage	Efficiency in Per Cent of High Task	Bonus in Per Cent of Base Wage
67	.0001	85	.0617
68	.0004	86	.0684
69	.0011	87	.0756
70	.0022	88	.0832
71	.0037	89	.0911
72	.0055	90	.0991
73	.0076	91	.1074
74	.0102	92	.1162
75	.0131	93	.1256
76	.0164	94	.1352
77	.0199	95	.1453
78	.0238	96	.1557
79	.0280	97	.1662
80	.0327	98	.1770
81	.0378	99	.1881
82	.0433	100	.2000
83	.0492	Increments of	Increments of
84	.0553	1% thereafter	1% thereafter

For piece rate from the last point, the increments would need to be 1.20% bonus per 1% production.

FIG. 25. Emerson Efficiency-Bonus Scale

psychology on the one side, and efficiency of administration on the other. If employees are not of the most ambitious sort, then **gradual upgrading** may be better than sudden change. If a company thinks it worth while to keep individual records of all efficiencies and to set up tables for payroll computation, then the Emerson plan can be used. Emerson advocated averaging a whole week into one calculation of efficiency, but that weakens any incentive and is not recommended for employees below foremanship. The whole question is a matter of policy and much depends on the history of any case.

Example of Emerson Plan.—Chicago Bridge & Iron Works used this plan based on carefully set job standards and the keeping of individual production records. The management claimed that it increased production and lessened supervision. A case is cited of an increase from 2,200 holes punched per day under former time plan to 6,000 per day under the Emerson plan.

The Ernst and Ernst plan secures the equivalent of the empiric curve by using a .6 constant sharing curve from point (75, 101) to point (90, 110) and a unity constant sharing curve, that is, basic piece rate, from point (90, 110) to point (100, 120). Beyond that point the 1.2 high piece rate is used (Auto. Ind., vol. 62).

ACCELERATING PREMIUM PLANS.—The Fair Labor Standards Act of 1938 made illegal for interstate commerce the lowest part of all earning curves which go to the origin. Although this portion of the curves rarely came into actual application, nevertheless it is now necessary to design plans that are wholly within the law. Of several possibilities the straight time wage 1.00 H_aR_h, and various percentages of that,

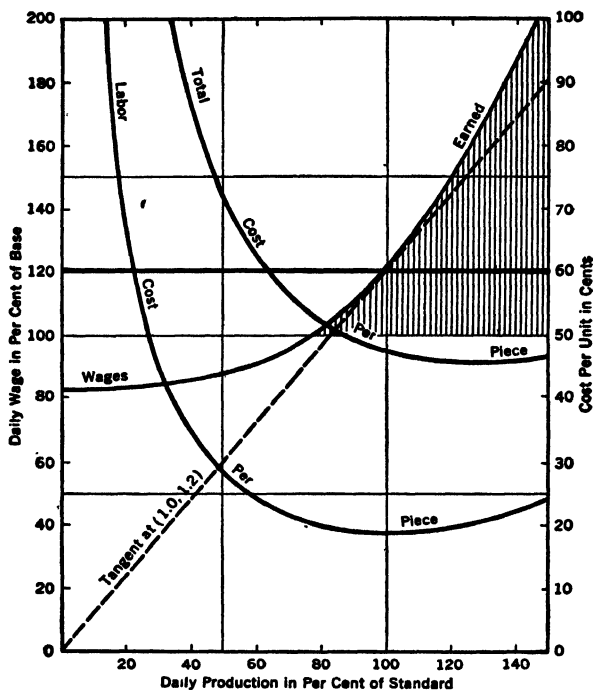



FIG. 26. Accelerating Premium (Parabola II) Plans

Per Cent of Production H_s/H_a	Per Cent of Total to Base Wage for Full Day $E/H_a R_h$	Total Daily Wage in Dollars E	Number Pieces per Day	Time Saved per 8-Hr. Task in Hours $H_s - H_a$	Labor Cost per Piece in Dollars	Total Cost per Piece in Dollars
0	83	3.20	.0	∞	∞	∞
1	83	3.20	2.4	− 72.0	$1.33	$3.05
2	83	3.21	4.8	− 32.0	.67	1.59
3	84	3.23	7.2	− 18.6	.45	1.10
4	85	3.27	9.6	− 12.0	.34	.86
5	87	3.34	12.0	− 8.0	.28	.72
6	90	3.46	14.4	− 5.3	.24	.63
66	92	3.56	16.0	− 4.1	.23	.59
73	96	3.70	17.5	− 3.0	.21	.55
79	100	3.84	18.9	− 2.1	.20	.53
80	101	3.88	19.2	− 2.0	.20	.52
89	108	4.16	21.4	1.0	.19	.49
100	120	4.61	24.0	0.0	.19	.47
114	139	5.36	27.4	1.0	.20	.46
133	207	6.78	32.0	2.0	.21	.45
145	221	7.95	34.8	2.5	.23	.46

FIG. 27. Accelerating Premium (Parabola II) Data

BH_aR_h, are best known but least satisfactory to an employer. Instead of making such guarantees, it may be sufficient to start at the legal minimum and provide increases from there on. As explained previously, some of the less-steep constant sharing plans can be arranged to start at this new locus and such arrangements are very satisfactory through intermediate efficiencies. They do not continue to be satisfactory, however, through points of high efficiency. If it is desired to have a single smooth earning line start at the legal minimum, pass some definite, high task-incentive earning point, and continue at a satisfactory slope, then a curve with an ascending slope must be used. Either the conjugate hyperbola or the vertical parabola can meet these requirements.

To show a specific case, the parabola will be selected and it will be started at point (0, 83⅓), which, according to regular assumptions, means at zero efficiency and $.40 per hour. Since the point (100, 120) is almost universal as a mutually satisfactory task-earning point, the curve will be passed through that point. One further condition is possible to the parabola whereby its slope can be shaped so that the 1.20 piece-rate line will be tangent to it. The curve, always accelerating, will diverge above this piece-rate line in earnings beyond high task (Figs. 26 and 27). The advantages of this single curve, or a family of them for various conditions, are obvious. The disadvantages are: (1) the formula is complex and requires an engineering mathematician for the design, (2) the lack of a step bonus will allow some scattering in response, and (3) the theoretical costs increase at the end. As to the first, all efficiency earning must be tabulated for practical payroll computation regardless of formula and when this is done the complexity of this plan ceases except that employees would have to be given "schedules" of efficiency-earning to satisfy their understanding. As to the second, a step bonus is a complexity in itself which is avoided elsewhere unless the machine rate makes conformity of response worth its trouble. Hence this plan is recommended for high-tempo work which does not involve heavy machine charges. As to the third disadvantage, the upturn of the cost curves, it would appear that in practice the total cost per piece will remain about constant at a level slightly above the low inflexion shown in the chart. This result would be consequent to the scattering already mentioned. That is, only the exceptional individuals would stay constantly at the highest points. The composite point for any group would not be excessive and would be justified in the time saved by that fraction of skilled employees who would exceed ordinary efficiencies. The principle of this plan is new but it has already been adopted by several companies, two applying it to supervisors. The derivation and manipulation of formulas for this and similar plans are given in Lytle's Wage Incentive Method (rev. ed.).

GROUP APPLICATION OF FINANCIAL INCENTIVE PLANS: DEFINITION.—

> A group incentive is any incentive applied collectively to two or more employees engaged in work which has the group characteristics; interdependent relationship between operations, consequent physical proximity and unity of interest.

Work with these characteristics requires cooperation and that requires close leadership. It is therefore desirable to break long sequences of

such work into small natural divisions which can be controlled by working leaders. Experience limits this kind of leadership to about 12 individuals, although there are many variables involved which may justify larger numbers. For instance, if a mechanical conveyor controls rate of production and if shares of work are well balanced, a larger number of persons may be successfully grouped. Conversely, if there is no mechanical control, poor balance of shares and, worst of all, no community of interest, then it is doubtful if the best of working leaders can get group action from even a few individuals.

Group incentive has three very definite applications where it may be decidedly superior to individual:

1. Conveyorized work where operators cannot produce any more work than is passed to them by the operators preceding them on the line of production.
2. Work other than conveyor where quality and handling of a previous operation can affect the subsequent operation to an appreciable degree.
3. Work of such a varied nature, both as to kind and quantity, as to make individual measurement impractical.

Job Standardization for Group Work.—Job standardization for group work tends to be crude. It sometimes is necessary to change the rate of production for a whole group, in which case either number of individuals or limits of group operation must be changed and individual shares varied accordingly. Even when operation as a whole is not changed, mature operators who leave or absent themselves must be replaced by beginners or substitutes and shares cannot be fixed for any length of time. The Western Electric Co. not only makes allowances in group rates for new help but it makes allowances for porterage, repair of defective work and supervision (A.M.A. Prod. Exec. Ser., No. 17). The time element, whether regulated by a conveyor or not, must be within the capacity of an "average" man because it is practically impossible to have all-star groups. Any stars who may be included come down in productivity as much as inferior ones come up.

Furthermore, **productivity per individual depends on the number of individuals in a group.** To reduce this number and increase productivity per individual, groups are often allowed to keep all or part of the earnings of any individual whose share of work they can take over, that is, in addition to regular earnings from any incentive plan. This is one of the exceptions in which employees do all the improving in method after the installation of an incentive plan and the saving from it should be credited to such improvement rather than to the regular incentive plan. While this possibility of elimination is cited by some as one of the advantages of group work, it is by no means the main objective. In fact, elimination of individuals, if ruthlessly accomplished, may destroy good relations and become a disadvantage of group work. After all, improvement of method is a management responsibility and although this "buck" can be mutually undertaken it should never be wholly passed to employees.

Suitability of Group Work.—The fact that quantity and quality of work are checked only at the last operation of the group has led some to claim that resulting **simplification of clerical work** is of itself enough to justify group work wherever possible Reduced clerical work may

be an important need but not if it involves much loss of working efficiency. The real objective of group work is facilitation of close cooperation where that is of supreme importance. Where close cooperation is not of supreme importance, it is more economical for all concerned to keep work on an individual basis, thereby stimulating maximum effort and allowing individual flexibility.

Group work, although older than mass production, has come into prominence through mass production, particularly in the automotive field where chain assemblies are the rule. From this success group work has spread to other fields and too frequently to work which entirely lacks group characteristics. During the late twenties there was a reaction and such companies as the Western Electric Co. tended to decrease the proportion of group work. About 15% of factory employees, or 25% of those on extra-financial incentives, are treated as groups and most of these are in conveyorized work (Fig. 1).

Group work must not be confused with product layout for the manufacture of parts and subassemblies in connected sequence. In this latter case, workers are not directly dependent, for their individual productions and efficiencies, on the work of previous operators.

Application of Group Plans.—The Wennerlund empirical plan (time rate to 75% high task, empirical bonus to 100% and high piece rate above 100%) undoubtedly has been more applied to groups than any other. The Manchester plan, which is similar except through efficiencies 75%–100%, is perhaps next in popularity. Various sharing plans such as Bedaux and Halsey (50–50) are common. Step bonuses at task, really two-rate time plans, appear under name of "group bonus," and straight piece rate appears under name of "gang piece rate." In fact, these last two names are so indefinitely used in the literature of the subject that it is impossible to make out what or how many earning curves have been covered by them. Probably straight piece rate is little used because so much group work depends on conveyors which are subject to interruption, and make a time guarantee necessary. When nonconveyor groups are made up of equally skilled individuals, rates per quantity of product from the group are practical, but when any groups are made up of unequally skilled individuals, as is frequently the case, rates must be expressed in time or in standard hours of work. With the latter expressions, individuals of different skills can all be paid on piece-rate earning curves but at different slopes, or they can be paid different hourly rates plus bonuses.

Again, bonuses can be divided equally among individuals or prorated according to time earnings. Thus, there are **numerous combinations with a wide choice of earning curves,** which permit the accomplishment of several objectives simultaneously. The task is likely to be low or intermediate, which would normally suggest a low-slope earning curve, but sharing plans do not have the simplest curves to calculate and simplicity is usually important. For this reason the piece rate on standard hour basis is popular above task and its steep slope is less likely to be abused in group applications than in individual applications. A time guarantee is usually necessary below task. Time payment is also used temporarily while beginners are acquiring skill.

Since a group task may be roughly set, group incentives are well adapted to take care of **maintenance gangs** and others on indirect pro-

duction, that is, work where the individual's share cannot be determined. They also provide an excellent means of including many such indirect employees with production groups. **Truckers, elevator men, set-up men, repair men,** and even **sweepers** concerned with a unit, may be included in the group and treated as direct producers, but they are rarely allowed more than 40% of the direct producers' extra earnings.

Emergency Use of Group Incentives.—After the United States entered the second World War, as a practical means of facilitating war expansion and its problems, such as skill dilution, it became the popular practice, particularly in Detroit, to forget many of the niceties of time study and put whole sequences of operations, even whole departments, on a single composite standard as per actual performance on a normal day. This achievement in standard hours was used as the basis for group incentives. The plan most used was piece rate figured in terms of standard hours and interpreted either as a

Premium, $E = H_a R_h + 1.00\,(H_s - H_a)\,R_h$, or as a

Bonus, $E = \left[1 + \left(\frac{H_s}{H_a} - 1\right)\right] H_a R_h$

The unions advocated this arrangement because the task was tested, because the group incentive never results in individual starring, and because all employees can share equitably in the cooperative gains. Management accepted it for other reasons: (1) because it was impossible to keep time study up with accelerating changes and (2) because lead men, skilled operators, etc., were merged with all others in a single group having a common interest, i.e., group success. With this mutual interest uppermost in mind, the lend-a-hand attitude, which is so necessary to help learners and inexperienced set-up men, is greatly encouraged. The best individuals can win only as the group wins. Furthermore, this make-shift standard can be reduced to a one-man basis and, as such, need not change as the manpower increases. Emergency practice of this kind should be accepted only for periods such as wartime. As a temporary arrangement it may be used to avoid permanent loosening of task standards. Aircraft companies followed the plan, based on weight of airframe produced.

Example of Group Plans.—Abbott Laboratories, Inc. used a Group Point Incentive plan (Fact. Mgt. & Maint., vol. 65). In the packing and shipping room, employing 20 persons, the basis of the bonus was three points for each order handled and one point for each unit included in an order. Bonus was 1% for each point, about 10,000 points per employee. A unit may be a single bottle of medicinal tablets, or it may be a previously packaged carton of 10 or 100 bottles or packages. Allowance of one point per item worked out with surprising fairness, despite range in item sizes. Likewise, three points per invoice was surprisingly equitable, though some invoices call for but one item and some are two or three pages long.

Changes in size of packages seem at first thought to work against the shipping room employees because, if business continued at the same level, though shipments are in larger units, there were fewer units on which to pay bonus. What happened was that paying a bonus on a unit basis helped to force shipping room economies. At first there were

four order pickers. With subsequent packaging improvements bonus fell off a bit, and when the next-to-best order picker left, the others found it possible to keep up with the work without hiring a new man. So, within a year, in spite of more business, there were only three order-pickers. These men were assured that in case of a temporary overload an extra man would be put on, but normally three were equal to the task. The remaining employees received more than the unreplaced man's bonus. In effect they split part of his pay.

Example of Calculation of Group Payment.—Suppose the department handled 10,000 orders in one month, and that these orders included 200,000 unit packages. If, to simplify figuring, allowances for absences and holidays are omitted, bonus, with 20 employees in the department, is figured as follows:

Orders handled	10,000	
Points per order	3	
		30,000
Packages handled	200,000	
Point per order	1	
		200,000
Points earned		230,000
Quota, 20 men		200,000
Bonus points earned		30,000
		.01
Bonus earned		$300.00
Bonus per worker		$15.00

In case the 20th employee was eliminated and his bonus split among the other 19, each would get but 75 cents per month additional. Instead, the bonus of the reduced personnel worked out in this manner:

Points earned, as above	230,000
Quota, 19 men	190,000
Bonus points earned	40,000
	.01
Bonus earned	$400.00
Bonus per worker	$21.05

Absences were deducted in figuring the bonus quota, in the following manner:

Departmental point quota, 19 × 10,000		190,000
Deduction for holiday, 19 × 8 hr.	152 hr.	
Other absences	104 hr.	
Transfers to other departments	37 hr.	
	293	
Points per hour	50	14,650
		175,350

It may be assumed that the 104-hr. deduction for absences is chiefly due to absence of two employees during one-fourth of their month. Under these circumstances, the bonus earned would be divided by 18.5, not by the normal 19. If the mathematical consequences of reducing quota for actual reduction in working hours caused by absence, and at same time reducing the bonus divisor, are figured out, the reason why employees are so willing to avoid overtime is revealed.

Plans for Learners and Apprentices

RATE OF PROGRESS IN LEARNING.—Age is believed to have little to do with the ability to learn. In fact, some investigators maintain that the general laws of learning apply with equal force throughout the age range of 15 to 50. The same rules of training, therefore, can be applied to all adult learners and response can be expected according to a single general curve, such as is given below. It should be remembered, however, that rate is relative only. Time taken will always vary with jobs and individuals.

Analysis of many thousands of cases provided the basis for formulating a curve (Fig. 28) showing the **average reaction of new employees to a task** with which they are not familiar (Bigelow, Mgt. Rev., vol. 17). It is often assumed, in working out plans for remunerating new employees, that a steady increase in efficiency should be expected from them. It is a fact that for the "average worker," when he or she has exhausted about one-half the normal training period, there must be expected a period of time, depending upon the nature of the work, where progress or skill practically ceases. Then after a short while he attains the balance of average proficiency very rapidly. Especially in plants employing female labor, loss of operatives before they have become fairly efficient is a serious problem, due largely to the fact that their remuneration is based upon a required constant increase in proficiency which is practically impossible for the "average worker" to maintain. The straight line approximating the learning curve is described under (40–60) Constant Sharing Plan as a substitute for Time Guarantee.

COMBINATION PLAN FOR BEGINNERS AND MATURE OPERATORS.—Since a piece rate is discouraging to a beginner, and a day guarantee is lacking in incentive, it is desirable to use a wage formula with an earning curve such as that of the Barth plan up to task (Fig. 21). It has been shown that this plan is not very effective for above task work, so it becomes necessary to combine with it one of the plans which is definitely effective above task. Although there are a half-dozen plans which might be so combined, the Gantt plan (Fig. 13) is particularly suitable. In this case the Barth formula would be applied to high task contrary to correct usage by itself. Alteration makes little difference in earning below task. The high piece rate (Fig. 9) could be extended back to (62–80) point and the step bonus avoided, but postponement is a better means of assuring at least task production after learning period. This portion of curve between 62% of task and task does not follow the learning progress curve (Fig. 28) but other parts do closely. Incidentally, this Barth-Gantt combined plan is one of the best plans for any employee new or experienced.

DECREASING AUXILIARIES FOR BEGINNERS.—Any rigid earning curve is sure to discourage some beginners because time of learning is an individual matter. For this reason it is common practice to devise some easily changed arrangement in which wages are based on length of new employment and rate of improvement. For instance, a beginner may after a day or so be put on **piece rate plus auxiliary sums.** The latter may be made to decrease from nearly a full day wage to zero, according to a table. The auxiliaries should be in percentage.

APPRENTICE RECORD

Name Mary Jones No. 161 Operation Trial Class II Training Period 6 Date Started 1/3
Address ______ Age ______
Experience ______
Education ______
Married ______ People dependent upon support ______
Born ______
Father Born ______
Where last employed ______
Position held ______ Wages ______
Where before that ______
Position held ______ Wages ______
Reason for leaving last job ______
Reason for leaving next to last job ______
Employed before by this Company ?
Under whom ______
Relatives employed here ______

Hours Worked	Wk.	% Efficiency Theo.	% Efficiency Actual	Pay Theo.	Pay Actual	Paid
48	1	15	18	11.50	11.50	✓
48	2	27	31	11.85	11.85	✓
48	3	34	38	12.20	12.22	✓
48	4	39	40	12.55	12.55	✓
48	5	42	44	12.90	12.90	✓
48	6	45	40	13.25	12.90	✓
48	7	47	50	13.60	13.60	✓
48	8	48	48	13.95	13.95	✓
48	9	49	54	14.30	14.30	✓
48	10	52	57	14.65	14.65	
48	11	58	62	15.00	15.00	✓
48	12	70	74	15.36	15.36	

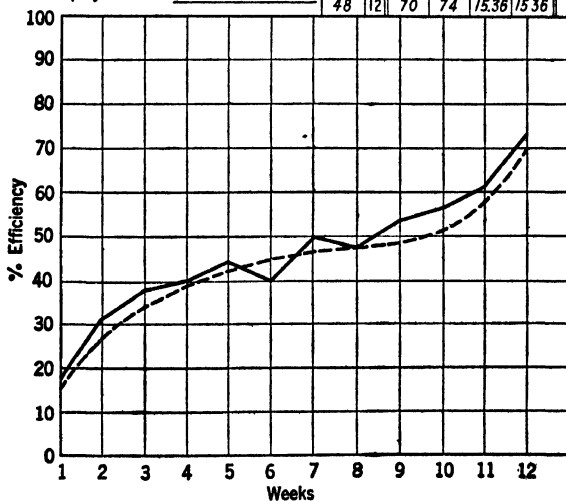



FIG. 28. Apprentice Record

INCENTIVES FOR APPRENTICES.—Long practice has demonstrated that a company using skilled men can always afford to maintain 12 to 15 apprentices to every 100 journeymen. With war pressure on manufacturing facilities, most companies had to go way beyond this norm. Even in peace times it would be foresighted to go beyond 15% since only about 60% of the boys who start such a course remain at graduation. In the United States, apprentices have usually been paid wages, but at a low rate plus a $100 bonus upon satisfactory completion of a full program. Except during war periods this program has usually extended over 4 years, or about 8,400 hr. The whole time is generally divided into eight periods and a change in wage rate is made at end of each period. These rates may be predetermined in per cent of the prevailing rate for common labor, in which case they exceed 100% after the first year, or they may be worked backward from the prevailing journeyman's rate as the 100% to be expected at the end of the program, in which case they start anywhere from 35% to 64% of journeyman's rate. The average rate in the United States machine-shop industries as of midsummer 1940 was 48.1 cents per hour against an average of 86.4 cents per hour for skilled workers (Personnel, vol. 17, and Bur. Labor Stat., Release No. 9780).

A few companies prefer to assign the **increased rates according to merit,** that is, without any announced schedule, but experience favors a known schedule. If the latter is used, some incentives may be obtained by allowing two or even three separate schedules. This method has been called the **X Y Z plan.** The X schedule is that of minimum rates. The Y schedule provides 2 or 3 cents more than the X schedule for the second period, and the Z schedule provides 4 to 6 cents more than the X schedule for the second period, and so on. Which schedule an apprentice will follow depends on his demonstrated merit, which is usually judged by the supervisor of apprentices, but it may be determined by the more formal method of merit rating if such a procedure is in existence at the plant. Naturally, these shifts in schedule may be worked both ways so that a negative incentive is in force as well as the positive one. On the whole, practices of large companies are at considerable variance.

Example of Plan for Apprentices.—Westinghouse Electric & Manufacturing Co. (Mech. Eng., vol. 48) has worked out a careful **program of promotion based on performance ratings** and leading by two charted paths to two different rate classes of trade work. These two paths have same rate advances, excepting at the last. Difference in paths is ingeniously arranged by time credits which shorten time intervals for better group of apprentices.

For a true preferred number series, a factor by which each item in the performance rating series is multiplied in succession should be derived:

Let f = Factor
Z = Last item in series
A = First item in series
n = Number of steps (number of items minus one)

Then for n series, $f = \sqrt[n]{\frac{Z}{A}}$

Series would be $A, fA, f^2A, f^3A \ldots\ldots\ldots\ldots\ldots f^nA$, or Z

With this formula, any desired number of steps may be set up between any two fixed values and resulting series will be truly geometric (American Engineering Standards Committee Report, June, 1927; Alford, Laws of Management Applied to Manufacturing; Inst. Mgt. Ser. 14).

These series are valuable for planning any promotion, but they are particularly so for giving incentive to apprenticeship.

Other incentives are: (1) job preference after graduation, (2) opportunities for specialized training, and (3) advancement as result of examination, all of which are nonfinancial. Still others of a financial nature may be used such as (1) provision of tools and textbooks, and (2) special bonuses throughout the program. Some companies allow piecework at certain stages of the program but this practice is questionable at any time, and definitely unwise in shorter, intensified programs.

Supplementary Incentives

INCENTIVES FOR QUALITY OF PRODUCT.—Recognition of superior workmanship on a given operation by means of higher than ordinary hourly rates is very ancient. Today, this practice is less justified on account of extreme subdivision of work and better control of tools, materials, etc. The present need, as a consequence of quantity incentives, is rather for an extra check on quality. The quality incentive is therefore a secondary measure and is usually applied in addition to a quantity incentive. It is often as bad for an employee to overdo a quality standard as to underdo it. Defects, accordingly, may have two fields, that is, a plus and minus set of limits. The nature and degree of these limits must be standardized for measurement and instruction. No bonus should be expected to maintain quality without a full program of design, purchase by specification, initial investment in equipment, maintenance of tools, use of gages, and suitable inspection (Trans. A.S.M.E., MAN-50-13). Neither should promotion be ignored as the inevitable hope of superior employees.

The **simplest plan for quality** consists in a fixed percentage premium for no imperfections, and deductions proportionate to the number or seriousness of imperfections. (An application to the paint industry may be found in Lichtner's Time Study and Job Analysis.)

Example of Quality Premium.—A simple quality premium was put into operation at Real Silk Hosiery Mills (Fig. 29). The plan applied to women, constituting one-twelfth of the employees. An inspector received neither a premium nor a penalty when her wrong classification was equal to 1.7%. This figure was set by careful analysis and represented a standard which allowed for human deficiencies for this particular work. When percentage of wrong classification decreased below 1.7%, the inspector received a premium which increased according to a graduated scale, as shown on schedule in Fig. 30. On the other hand, when the wrong classification exceeded 1.7%, a penalty was imposed, as shown on this schedule. The per cent of wrong classification was obtained by the check of reinspectors who were paid flat salary. Occasionally, super-reinspection was made on the part of the superin-

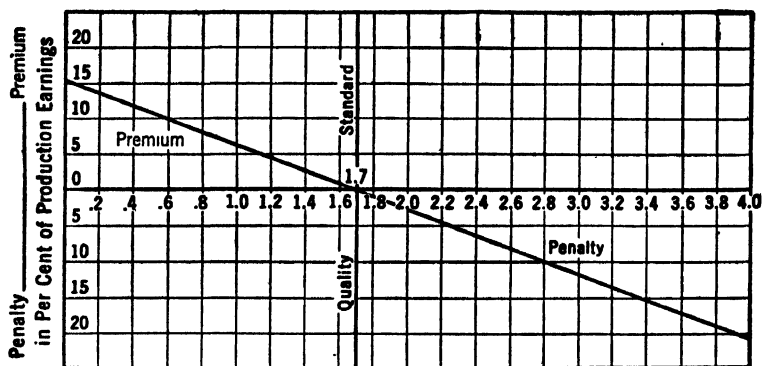



Fig. 29. Quality Premium Chart for Knitting Hosiery

Per Cent Wrong Classification	Premium of Production Earnings	Per Cent Wrong Classification	Penalty of Production Earnings
0	15.3%	1.8	.9%
.1	14.4	1.9	1.8
.2	13.5	2.0	2 7
.3	12.6	2.1	3.6
.4	11.7	2.2	4.5
.5	10.8	2.3	5.4
.6	9.9	2.4	6.3
.7	9.0	2.5	7.2
.8	8.1	2.6	8.1
.9	7.2	2.7	9.0
1.0	6.3	2.8	9.9
1.1	5.4	2.9	10.8
1.2	4.5	3.0	11.7
1.3	3 6	3.1	12.6
1.4	2.7	3.2	13.5
1.5	1.8	3.3	14.4
1.6	0.9	3.4	15.3
1.7 (Standard)	.0	3.5	16.2
		3.6	17.1
		3.7	18.0
		3 8	18.9
		3.9	19.8
		4.0	20.7

Fig. 30. Quality Premium Schedule for Knitting Hosiery

tendent or his assistants, to verify the findings of reinspectors. These precautions were taken to insure that all products were properly shipped according to style, size, and color.

The schedule also indicated weights of different kinds of imperfections on a point basis which, in turn, determined per cent on classification. Inspectors were paid according to production, and the per cent premium or penalty was applied to production earnings. Fig. 29 shows a graph of this quality premium schedule.

Rules for calculating the premium are for each .1% increase over 4% imperfections to increase the hourly penalty .9%. Multiply the percentage by piece-rate earnings to determine the premium or penalty in money. Imperfections are determined weekly by points; 25 points equivalent to one imperfection. Fig. 31 gives imperfections with their standard point equivalents.

Imperfections	Standard Points	Imperfections	Standard Points
Hole	50	Pull Threads	20
Seconds	50	Mismate	10
Mend	40	Reboard	10
Irregular	30	Redye	10
Firsts	30		

FIG. 31. Points for Imperfections in Knitting Hosiery

An important feature of the plan is posting results. Girls' names are listed in order of accomplishments. Number of imperfections is placed after names and a red line is drawn at location of no premium. No additional clerks are required. This system has given good results and the principle proved to be correct and fair.

INCENTIVES FOR REDUCING MATERIAL WASTE.—Waste elimination incentives, as they are usually called, are those "employed with a view to reducing to a minimum usable material wastes resulting from manufacturing processes (A.M.A. Prod. Exec. Ser. 65). They are used only where cost of material constitutes a large proportion of total cost, or where the likelihood of much waste amounts to the same thing, notably leather, textile, paint, wood, and food industries. After the most economical processing procedure is established, experience data may be recorded and standards of waste formulated. In few cases is it practical to strive for zero waste but there is a **most favorable per cent of waste** for every case. Time and motion study are as essential here as for any other phase of task standardization. Standard written instructions are made up and employees taught how to carry them out.

The **incentive plan is simple.** It provides a bonus related inversely, or nearly so, with the amount of waste per unit of product or per man-hour. When effort involved is directly proportional to saving accomplished, the curve plotted between per cent of waste and bonus is a straight line. When effort must increase more rapidly than saving, the curve may be a parabola or something approaching that shape. The bonus thus earned is usually independent of any quantity bonus and may or may not be accompanied by it. A waste bonus may be applied either to

individuals or to groups. If properly managed, this practice should be in no way negative or penalizing. The plan is simple and automatic. It does not fail to work after the novelty wears off as sensational prize campaigns so often do. Many of the incentives against waste have emanated from Bigelow.

Examples of Waste Bonus.—Joseph Stern & Sons Co. used an inverse bonus which applied to spoiling of hides by the carelessness of skinners. A schedule was made between percentage of cuts to number of hides skinned and an inverse bonus. Men worked in groups and received a quantity premium as well as waste bonus. The plan also worked well when applied to cutting of shoes. Three per cent more material was saved by this means.

T. M. Sinclair Co. applied waste bonuses to power plant operation. Percentages of CO_2 were obtained by an automatic CO_2 and draft recorder and a schedule of corresponding bonuses was established.

At least 10% CO_2, but no more than 14%, is desired. At that point, CO appears which indicates incomplete combustion. Standard performance results on three boilers are shown for a single 8-hr. shift in Fig. 32. It was also necessary to have a penalty on percentage of combustible in the ash. This was established empirically and shown by a curve (Fact. Mgt. & Maint., vol. 77).

	Small Boiler	Large Boiler	Head Fireman	Total
CO_2	10	12	....	....
Savings	1.06	1.14	....	3.34
Bonus	.26	.28	1.00	1.82
Savings to Company	....	....	....	1.52

FIG. 32. Savings from Carbon Dioxide Bonus

Mohawk Carpet Mills presents an example (Fig. 33) of waste incentive applied to rug weaving which is of particular interest because relation of effort to results varies as a parabolic curve, rather than as a direct proportion.

Each line in an Axminster rug is "set" on a loom spool. With no waste whatsoever it should be possible to weave a maximum of 125 rugs from one set. Because of inherent loom operations this maximum is difficult to secure. However, the standard of 115 rugs was set as a minimum to be woven by an operator. The operator, through careful loom operation in keeping waste to a minimum, could increase the number of perfect rugs woven. It was much more difficult to operate, conserving material, so as to produce the 123rd rug than to produce the 116th rug, which was but one in addition for the standard set. A higher incentive, therefore, was justifiably paid the operator for the 123rd rug than for the 116th rug. A maximum incentive was paid for the 125th perfect rug.

Defective Quality and Waste.—In some cases a waste elimination bonus may bear upon number of defective units finished as well as upon number of units of raw material. That is, where no seconds are usable, waste and quality problems become identical.

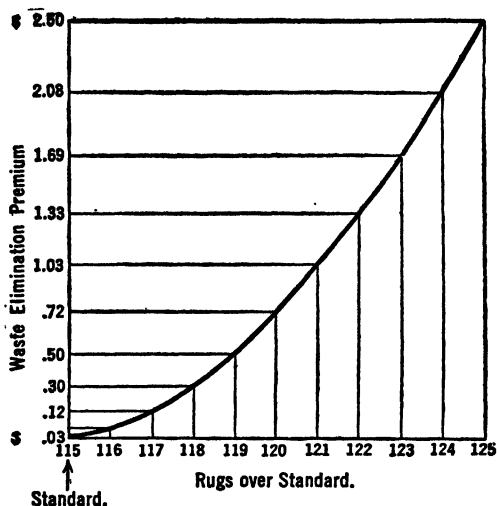



FIG. 33. Waste Premium for Rug Weaving

In most kinds of work defects can be tolerated down to some limit below which the article cannot be accepted. The Shuron Optical Co. recently met this situation by establishing standards for all three requirements—quantity, quality, and "shrinkage." It then developed three bonus formulas to reflect three different sets of existing conditions.

$$\text{Bonus in \%} = \left[.6 \frac{\text{Production}}{\text{efficiency}} + \frac{\text{Quality}}{\text{efficiency}} - \left(\frac{10\text{—Shrinkage}}{\text{efficiency}} \right) \right] - 100$$

Formula 2, here shown, provides .6 credits for production variations from 60% to 120% and full quality variations from 50% to 100% but also provides debits for shrinkage variations exceeding 10%. All of these variations are empirically scaled in a four-column 19-row table which allows high quality or low shrinkage to offset loss of production to some extent. This incentive is applied to groups ranging from 5 to 30, is calculated daily, and is paid weekly. The bonus averages 27%.

INCENTIVES FOR ACCIDENT PREVENTION.—Any deviation from correct motion, method, or plan may be looked upon as a potential accident. Although relatively few of these deviations develop into lost-time accidents, nevertheless it is management's interest and responsibility to take precautions against all such potentialities. Economies alone justify preventive actions but humanitarian interests urgently demand them. Progress has been made, particularly in safety devices and in orderliness of materials handling, but the human element remains difficult to influence. The usual appeal to employee cooperation has been through house organ, poster, committee propaganda and other nonfinancial incentives. Financial incentives have been restricted

in the main to prizes. The characteristic effect of a prize is temporary, even exceptional, so that prizes do not provide a constant and general influence. Regular financial incentive plans as applied to waste of material may be applied to waste of life and limb. The nearest approach to this practice so far appears to be the use of fixed bonus funds minus penalties and only a few companies have gone this far.

Example of Accident Prevention Bonus.—Newport News Shipbuilding & Drydock Co. used, among its 14 incentive plans, a bonus fund applied to accident prevention. Rewards of this plan were paid to members of the yard committee on safety. A safety reward was paid in addition to production rewards. The production reward for most employees was a Halsey premium and for supervisors a possible 5% of salary bonus. The safety men might or might not be supervisors.

The management set aside $10,000 each year for safety bonuses. Bogies were set up in five steps according to amount of lost time (Fig. 34, column 1). This $10,000 fund was reduced for each accident at yard according to a money scale (column 2). Whatever sum remained after these reductions was divided, one-third to representatives and two-thirds to committee men, but was not paid until after further reductions were made for individual liability.

	(1) Lost Time in Days	(2) Reduction of $10,000 Fund in Dollars per Accident	(3) Reduction of Personal Share in Per Cent per Accident
Class 1.......	Less than 7	$ 10.00	.010%
Class 2.......	7 to 43	25.00	.025
Class 3.......	43 to 70	75.00	.075
Class 4.......	Over 70 but not permanent	150.00	.150
Class 5.......	Permanent	250.00	.250

FIG. 34. Schedule of Penalties for Accidents

These further reductions were figured in certain per cents per accident within each man's group (column 3).

The first effect of this plan was to **reduce the number of infection cases** due to unreported minor accidents. The company record for two successive years showed:

A reduction in frequency rate from 24 to 16 accidents per 1,000,000 hr. of work (33⅓%).

A reduction in severity rate from 1.92 to .83 days lost per 1,000 hr. of work (56%).

INCENTIVES FOR ATTENDANCE AND PUNCTUALITY.

—Any good incentive on production tends to improve regularity, particularly if it is a group application. If there is little trouble from absence or tardiness, it is a questionable practice to arrange a special incentive for regularity. There are, however, industries which have a distinct attendance problem. For instance, women employees who

merely wish to add to the family income but who do not carry the entire support, are prone to take days or half-days out for the sake of home duties. High wages contribute somewhat to absenteeism of certain kinds of employees. This irregularity is disturbing to factory control and a real source of inefficiency in prosperous times. Without a special incentive it is customary to hold irregularity against an employee by some or all of the following means: lay-offs, salary or wage reductions, deferred promotions, deferred wage increases, postponement of vacations, vacation reductions, unfavorable notation on personnel records, loss of extra time, assignment to less desirable kinds of work, and use of visiting nurses to follow up absentees. These means will doubtless continue to some extent where a special incentive is used, but, if they can be relinquished in part, the feeling of penalty will be relieved. **Percentage bonus is the most common device.** Such bonuses range from 3% to 10% of regular wage. The difficulty is to set them up so that they will reach the chronic offender after a short loss of time during the work period. An employee may be credited a flat 5% of his wage payable at end of a perfect month, or he may be credited 3% the first month, 4% the second, and 5% the third.

A few companies allow certain **time off with pay,** such as one Saturday morning a month, when absence is least undesirable. This plan is also applied on a group competition basis. The department which has the best record in the month is allowed a Saturday morning off. Each man-day absence counts one unit against the record, and each tardiness counts .3 of a unit against the record. Where there is much commuting, exemption is made for late trains or specific tie-ups. With flexible and humane administration, the plan has been successful to the extent of reducing absenteeism, in two representative actual cases, to 4.5 and to 3.2% (A.M.A. Prod. Exec. Ser. 66). Periodic posting of records is a strong nonfinancial incentive.

Example of Regularity Bonus Plan.—Leeds & Northrup Co. for many years applied an attendance bonus plan. No additional clerks were needed. The plan was briefly stated in an Employees' Handbook.

"If the weekly time card shows that an employee has been on time every morning and afternoon and not absent from the plant at all during working hours, he will receive on pay day a bonus equal to 5% of his week's wages. To make allowance for absence or lateness for unavoidable causes, he will still receive his bonus if he is absent or late not more than once during any one month. If he has a perfect attendance record for three successive months, he will be allowed two such absences or latenesses without affecting his right to receive the attendance bonus."

Number of latenesses	1.85%
Days of absence	2.87%
Cost of bonus	$21,571
Possible bonuses lost	1.05%
Bonus earned averaged	4.47%
Days absent throughout the metal trades in the district for year	5.1 %
Days absent from company for year	2.87%

FIG. 35. Typical Record of Absences

The management offered an excellent audit of the plan covering the second period of its 10-year try-out (Fig. 35). This company also paid a 5% bonus for bringing in a new employee. But this was not done until the new recruit had completed 13 weeks of work.

VACATIONS WITH PAY.—A study of vacations-with-pay plans made by the National Industrial Conference Board (N.I.C.B. Studies in Personnel Policy, No. 21; for specific plans see also N.I.C.B. Research Memorandum, No. 5) gives information contributed by 495 representative companies regarding policies for their wage earners and 356 establishments regarding policies for their salaried employees.

The trend toward revising and liberalizing vacation provisions has continued since the Board's survey of 1939, since one out of every ten replies indicated that changes have been made or are contemplated for this year.

In slightly over one-half of the manufacturing establishments, the plan for wage earners provides for vacations of varying length, graduated on the basis of past service. In the nonmanufacturing companies graduated plans are twice as prevalent as the uniform type plans, which provide the same length of vacation to all employees who can meet the established service requirement.

Of the 495 plans **for wage earners,** the maximum amount of vacation granted is one week in 57% of the companies, over one week in 42%, and less than one week in only 1%. Three weeks' vacation or more is granted to wage earners with long service records in 21, or 4.2%, of the establishments.

The **vacation policy for salaried employees** is generally more liberal than that for the wage earning group, although 70 companies reported that their policy is the same for all employees.

Of the 356 plans applying to salaried employees, the maximum amount of vacation granted is one week in 9% of the companies, two weeks in 85.4%, and three or more weeks in 5.6%.

Selection of Financial Incentive Plans

DETERMINATION OF POLICIES.—While the problem of selection of a wage incentive plan is difficult to treat in general, it is not difficult to solve in a specific case. Most any concern will have had experience with one or more plans and from that experience can set up its own list of risks it wishes to avoid and objectives it wishes to attain. An incentive plan is best only in the light of conditions which it must fit. There are, however, a few principles which may be used for guidance. The first consideration must be **direction of change desired,** consistent with all company policies. This requirement may be met by having a management committee apply the Dennison classification (Fig. 36) to the given conditions.

The two divisions of classification of Fig. 36, designated as policies A and B, provide a choice of extreme strategies. It is possible to follow both policies in some respects by using two plans separate in purpose, but harmonious in application. For instance, any one of the financial incentive plans may be used under policy A on individual production, and some plan for publishing production records may be used as a nonfinancial incentive, a policy B item. Whether or not there are separate plans to accomplish both policies A and B, it is permissible to zigzag

Policy A Immediate Stimulation of Effort Emphasis on "star" performance Usually small-scale, noncontinuous process	Policy B Long-Run Stimulation of Teamwork Emphasis on organization performance Usually large-scale, continuous process
1. Individual Application It is strong but noncooperative.	1. Group Application It is weak but cooperative.
2. Cash Reward ("Extra-Financial") It is strong but temporary.	2. Nonconvertible Stock Reward It is weak but persistent.
3. Low Rate with High Bonus It is strong but does not facilitate hiring. A low rate means a high production task.	3. High Rate with Low Bonus It is steady and facilitates hiring. A high rate means a low production task.
4. Fluctuating It is strong but discouraging to some.	4. Nearly Constant It is weak and bonus considered as part of rate.
5. Systematic } Provides advance understanding but requires experience. It avoids jealousies.	5. Arbitrary } It allows consideration of the intangibles but causes recipient to guess at what is wanted and to cater for favor.
6. Public }	6. Secret }
7. Financial (See further subdivision in Fig. 3.)	7. Nonfinancial
Matter of Emphasis	
It is immediate but requires the support of other measures to take care of quality and teamwork. This division is older and less experimental.	It is the only way to the correct mental attitude, loyalty, etc., but must be backed up financially. This division is newer and more experimental.

This classification was given as a paper by Dennison before Winter Convention of American Management Association, 1928, and was put into diagrammatic form by Lytle.

FIG. 36. Classification of Incentives According to Policy

across divisions of this classification, instead of going straight down on one side through all seven items. For instance, company policy could include:

B_1 Group bonus
A_2 Cash reward
A_3 Low rate and high bonus (with its corresponding high task)
B_4 Nearly constant
A_5 Systematic
A_6 Public
A_7 and B_7 Financial and nonfinancial combined

The Gantt plan applied to a related group would exactly fit all these conditions. Items B_5 and B_6 are justified only as temporary expedients while experimenting with a new plan, and then only in the case of incentives for executives. Fig. 36 is not intended for use in selecting a specific plan, but rather the executive policy which a plan is to satisfy.

A second consideration is **apportionment of weights to fundamental interests** which will assure each one its proper emphasis. There are three of these interests connected with every job: (1) quality of work, (2) quantity of work, and (3) economy in use of materials. The relative importance of these fundamentals varies widely, and a requirement of a well-determined wage incentive is that it shall correctly reflect the relative importance of all three. As in job evaluation, **fundamentals of quality, quantity, and waste** can be understood only by thorough job study. Alford puts the relationship of task to incentive into three concise laws (Laws of Management Applied to Manufacturing). It is evident, therefore, that little should be expected of any incentive until job standardization has been used to establish standards for all of these and related matters.

QUALITY STANDARDS.—Specified tolerance with "go" and "no-go" gages for machine-shop practice are in general use, but definite quality specifications and tests for other materials are not in general use. In the textile industry the proportion of certain imperfections which may be tolerated per inch of weave are now being standardized in plant laboratories. In chemical processes, where imperfection may be equally allowed on either side of a standard, plus and minus tolerances are set so that an operator exceeding the allowed error in either direction is graded a definite amount less than task. By use of recording instruments, Wolf has established such specifications on temperature, moisture content, pressure, etc., on wood-pulp cooking. Lichtner has established written specifications for mixing of colors, etc. Shewhart has developed statistical solutions for sampling in connection with quality control.

WASTE OF MATERIAL STANDARDS.—In many industries the value of material used is greater than value of labor. In leather work it is more important to secure the maximum number of units from a skin than to save too rigidly on labor. For example, if the cost of a certain piece of leather is 10 times the labor cost of cutting it, it is to the interest of management to reduce spoiled pieces even at a slight reduction in output. It is better to cut 10 pairs of shoes and spoil no leather than to cut 15 pairs in the same time and spoil one. In the wood industry, Bigelow has established standards of waste on which bonuses may be paid inversely to the amount of such waste. Where no seconds are usable, waste of material and quality of product merge into a single problem.

QUALITY AND WASTE CONTROL BY INDIRECT MEASURES.—Unless quality or waste is extremely important, it is sufficient to enforce those standards by inspection and to make fulfilment of them a prerequisite to any quantity standard. Such a prerequisite necessitates more attention to inspection than is usual for work done without quantity incentive. The first reaction of foreman to a quantity incentive is apprehension for quality. He knows that more quantity may easily

be attained at the expense of quality. When inspection is well enforced, however, there need be no conflict between quantity and quality, or quantity and waste. The most usual problem is to provide reasonable protection for quality and waste by inspection and at the same time put all possible emphasis on quantity. **Strong inspection** with definite specifications is, therefore, a **necessary accompaniment of any quantity incentive.** A supervisory incentive or nonfinancial incentive may also do much toward the same end through general cooperation. In many cases it seems justifiable to spend somewhat less on direct quantity incentives and more on these indirect measures. The whole thought may be summed up in this general principle:

> Determine the interests of management, specify them definitely, provide tests and checks, and then arrange incentive details so that the interests of the employees will coincide with the interests of management.

AN INCENTIVE SHOULD NOT BE EXPECTED TO STAND ALONE.—Broadly speaking, good management is in itself an incentive and without it no special incentive can be entirely successful. An incentive plan should automatically promote all phases of management control, but management should not neglect any phase. Overlooking this fact is the greatest danger with group incentives. If the hour or minute is used as a basis of figuring earnings, as it can be used even for piece earnings, weighted points may be made to assist all the way through. Such a unified system can be superior to one in which these measures function independently. Taylor, Gantt, and Emerson all aimed in this direction, but Bedaux, Parkhurst, and their followers have gone farthest in unifying incentives with production control.

ESSENTIALS OF A GOOD FINANCIAL INCENTIVE PLAN.—An incentive plan is no cure-all. It is not even a primary remedy for industrial ills, but a phase of control effective only after such primary measures as correct processing, improved layout, job standardization, and job evaluation have been thoroughly carried out. Overdoing an incentive is as bad as underdoing it. It is impossible to set up a single set of ideals for all plans. Special conditions have special requirements and no one plan should be expected to meet all opposing conditions. In general, however, an incentive plan for ordinary manufacturing departments should possess most of the following characteristics. It should be:

1. Just to both employee and employer and ultimately contribute to the benefit of both. Reward should be positive and material, not negative or unnecessarily punitive. Its operation should promote confidence.
2. High in task and in reward. The latter should, as one writer aptly puts it, "reflect an employee's contribution to his company's success." Generous reward encourages effort to meet high standards. [Taylor insisted that a successful plan should offer: (1) laborers, 30% to 60% more than class; (2) ordinary mechanics, 70% to 80% more than class; (3) skill, brains, close application, and bodily exercise, as high as 100% or more beyond class. These percentages are too high for present-day practice because task standards are far higher today than was average performance before time study and job standardization came into existence.]

3. Sound enough in measurement to guarantee against rate changes until operation method is changed. That is, earned reward will be paid.
4. Reasonably simple for the employee to figure or understand its relation to individual or group performance, practical in shop procedure. Results should be available over as short a period as the accuracy of rates will permit.
5. Adapted to augment and be capable of use with other management controls.
6. An aid to teamwork and automatically assist supervision in a practical manner.

Management should:

1. Obtain complete employee support of the plan.
2. Avoid a paternalistic attitude.
3. Give full support in matters of production, material and quality control, maintenance, and nonfinancial incentives.
4. Refrain from dropping the plan as a means of wage reduction in dull times.

PRODUCTION A RESPONSE TO EARNING.—The whole earning curve is of interest to the individual employee, for he may be at different efficiencies on different days; but the employer is most interested in a single point or narrow range of points at which a given plan will hold average production day after day. In fact, no other point on the direct labor cost curve has anything to do with overhead cost in practice. This "average response" point varies between the plans and for a single plan in different installations, but it varies little from day to day for any one installation. As an incentive to the employee, the amount of earning is psychologically the independent variable and his production is a response. From this viewpoint, **high earning is prerequisite to high production.**

CONFUSION BETWEEN LABOR AND TOTAL COSTS.—Fallacious thinking by employers in the matter of wages is usually due to too much thought of **direct labor unit cost** and too little thought of **total unit cost,** that is, failure to consider a department as a whole. Selling price must include overhead as well as labor cost. Material cost is often independent of operating efficiency. Therefore, total cost per unit is the only true criterion of company results. Total cost per unit is inclusive and in no way dangerous. The fact that for a fixed overhead total costs per unit decrease as production increases is the foundation of the philosophy that **low wages do not mean low final costs.** Were it not for this overhead-volume relationship, the lowest earning curve would be unquestionably the best plan.

There is one case in which overhead is likely to increase due to incentives. There is a growing tendency to pay some kind of incentive to every one, from foreman on up. When this is done, overhead will be affected by any new incentive installation and overhead per piece may not materially go down as production increases. If overhead costs have the proper weighting in executive plans, however, savings in overhead will more than compensate for bonuses paid.

REDUCTION IN LABOR COST COMES FROM JOB IMPROVEMENT.—**Higher individual earning and lower unit labor cost** can be combined only by eliminating waste labor through improve-

ments in machinery, methods, or control. By this means motions, sub-operations, or whole jobs may be eliminated, and the same net results secured with fewer kilo man-hours. Employee assistance to this process may come as a result of an incentive, especially if it is a group plan, but such a result is incidental and not a major expectation. In comparing any two incentive plans, it can usually be ignored. An incentive plan is primarily an operating mechanism. Any piece-rate plan has the same direct labor cost per unit for small and large productions, that is, production varies directly with wages. Such labor cost per unit cannot decrease as production increases! Any earning curve having a slope less than piece rate does give increasingly less cost per piece as production increases, but this kind of reduction in labor cost is also a **reduction in wages per piece.** The old way of paying a decreasing amount for higher productions and getting such productions by driving methods is practically gone. By such means a fairly high daily earning was possible with a low unit labor cost.

COMPARISON OF INCENTIVE PLANS BY THEIR TOTAL COSTS.—In comparing one incentive plan with another, job standard must be considered as already improved and fixed. In these circumstances it is a flat contradiction to speak of lowering labor costs simultaneously with raising wages; they are exactly or nearly one and the same. Total costs, however, are reduced as wages are raised, under an effective incentive plan. Overhead tends to remain practically constant in spite of increased production, under the installation of a strong incentive as compared with a weak incentive. There are sufficient labor savings to offset any minor increases in overhead.

If direct labor were the only consideration, there would be no purpose in considering the high piece rate for an instant, but since average production is sure to be higher under the sharper-sloped piece-rate earning curve, it is only a matter of enough additional response to reach a considerably **lower total cost,** despite **higher labor cost.** Total cost is the deciding factor since it is inclusive of all costs.

> Stated as an economic principle, when one incentive plan succeeds in holding the average production response at a higher efficiency than another incentive plan, the nearly constant overhead is distributed over more units and the overhead per unit is reduced.

Consequently, total costs per unit between two incentive wage plans may be: (a) equal despite different direct labor costs per unit, or (b) less in case of the one having the greater direct labor cost per unit.

ESTIMATING RESPONSE TO BONUS PLANS.—After setting a standard task, possible percentage of increase in production may be figured by estimating actual time and then using the formula (Lichtner, Time Study and Job Analysis):

$$\text{Increase in production} = \frac{\text{Actual time} - \text{Standard time}}{\text{Standard time}} \times 100$$

If actual time represents average performance or can be made representative by many applications of the formula, then the resulting percentages will indicate the probable increase. It is rare, however, to find a department where the range of performance is not widely scattered. Lichtner found from experience that the **average employee would make**

bonus only 85% of the time. This, of course, includes some performances above task, and many just below task. Using this same factor he derives what he calls "proposed wages," which he gives in a similar formula:

$$\text{Increase in wages} = \frac{\text{Proposed wages} - \text{Present wages}}{\text{Present wages}} \times 100$$

$$\text{Saving per hour} = \text{Present cost} \times \left(1 + \frac{\text{Increased}}{\text{production}}\right) - \frac{\text{Proposed}}{\text{cost}}$$

In one application of these formulas, Lichtner found the increase in production to be 45%, increase in wages 29%, and decrease in total cost per year $40,630.68. For the relationship of plan characteristics to working conditions, see the paragraphs headed "Application" of the various plans.

DECIDING ON THE EARNING CURVE.—When conditions and methods have been improved, as far as may be expedient, specific jobs standardized and evaluated, incentive policy and desired emphasis determined, then management is ready to adopt, modify, or design the most suitable earning curve for each particular set of jobs. Usually a plan applied for like conditions elsewhere is adopted, because it is thought that adoption will avoid all experimentation. Actually there is bound to be some experimentation even in exact copying because some minor conditions, if only the personal factors, can never be found identical in any foregoing case. The history of the situation also is virtually unique and that alone has an important bearing on what earning curve will be most suitable. Hence it is not necessarily more experimental to modify a plan, or to combine portions of different standard earning curves, than to install some plan directly, provided the changes are made in conformity with the correct principles. An entirely new design should be safe in competent hands, but there would be some experimental risk even when it is kept within correct principles. Whichever of these means is followed the same steps are involved, namely, to:

1. Ascertain the kind of task—high, intermediate, or low.
2. Set the necessary total earning to get task efficiency.
3. Estimate the desired average response in terms of efficiency and earning.
4. Know the degree of machine charge or overhead involved.
5. Bear in mind the history of the case, union attitude, and other factors.

From steps 1 and 2 one point on the standard chart will be determined and can be checked in its relation to the basic point (100, 100). From step 3 a higher point will be determined. This point is the most difficult since it can be judged only from experience with similar conditions, some of which may be illusive. Consequently, this point should be assumed conservatively and tentatively. From step 4 it will be evident whether a step bonus should be inserted. If a single step is desirable, its amount is determined by the vertical distance from normal time wages to necessary earning at task, step 2.

Various earning lines may now be drawn to conform to the above determinations, compromises made if necessary, and all checked against step 5. No one should attempt the design of an earning curve who has

not had considerable experience with the kind of jobs involved, the particular human factors present, and, last but not least, with the principles treated at length throughout this Section. Little has been said about the cost curves which accompany each plan. At this stage they should be worked out so that a full realization may be had of what is involved, for the likely range of efficiency, particularly for the estimated point of average response.

INSTALLING A NEW PLAN.—A good incentive plan should benefit employees as well as their employers, but union leaders may be predisposed against incentives and some employees are suspicious of all changes. Hence the leading employees and union representatives must be consulted and satisfied in advance. This work is sometimes difficult and may require considerable attention. Printed illustrations of various earnings may be helpful because money is one of the first interests of the employee. A conference should be held in which employees are allowed to express their point of view. When large numbers of workers are involved, department groups or even operation groups may be consulted separately. Leaders among the employees who are intelligent and influential should be won and put on the new plan one by one. These leaders, when convinced of the plan's merits, will bring their friends to desire the same advantages. By this means advance opposition should not develop. If a plan will not work with a few, it will not work with many. There should be no great haste. Failure in introducing a wage incentive plan may forfeit much of the benefit anticipated from expensive job standardization.

DISASTROUS EFFECT OF DISCARDING INCENTIVES.—Employees successfully responding to an incentive plan, and, accustomed to high job efficiencies even for years, will immediately drop back to their usual low daywork efficiencies when for any reason they are deprived of the usual incentive. Companies have been known to push an incentive plan during a prosperous period and then discard it as soon as orders decreased. Employees once treated this way will not have much heart in supporting the next production campaign.

COST OF INSTALLATION.—Cost of installation is variable and any data regarding it are of questionable value. It may be of interest, however, to state that one company of consultants charged $500 a week for complete service. This included one full-time man and, in addition, two supervisions, that is, weekly calls from a field engineer and monthly calls from a man still higher in the organization. Installation was done completely and a permanent man was broken in. **Time taken was never less than six months** and was usually from one to two years. Other consultants do no more than to advise and break in resident staff men.

Financial Incentive Plans for Indirect Production

CHARACTERISTICS OF INDIRECT PRODUCTION.—Most indirect production jobs are alike in that they are irregular either as to conditional requirements or as to schedule requirements. In the former case they cannot be standardized without considerable expense, and in the latter case they may not be standardized merely from neglect. The result either way is an indefiniteness which defies planning or budgeting

and which precludes any use of extra-financial incentives to expedite such work. Excuses for the exemption of such activities from incentives are in themselves evidence of neglect. With an increasing dependence of direct production jobs upon such indirect production functions as **maintenance, material handling, stockroom work,** and similar services together with an increasing proportion of indirect production costs to direct costs, a different value is now being put on these neglected jobs. Most companies are at least setting up standard ratios between indirect and direct labor costs beyond which the former is not allowed to extend. This practice has the danger of discouraging any increase in ratio whether undesirable or desirable, but it is knowledge gained and if given some flexibility may serve as a rough standard.

Many companies have made a mistake in treating **too many expense items as a direct ratio.** Most overhead accounts under reasonably good management follow very definite mathematical relationships with other factors of the business. In very few cases can this relationship be expressed accurately as a straight ratio of direct labor (or of any other factor) for different volumes of production. The result is that ratios set up for normal production are off considerably in subnormal or abnormal periods. It is much better to separate such work into natural units of character, department, etc., and still better to work out exact motion-time standards for all true elements of work which can be synthesized into any possible combination. This latter procedure requires time as well as money and may not always be justified, but it is as flexible as it is accurate and may in the long run cost less than other procedures. **A rough standard is better than none** and with a proper selection of an earning curve, the roughest standard may have an extra-financial incentive applied with some success.

Regardless of the kind of standard, it is also characteristic of much indirect production that effort and effectiveness do not vary directly. For instance, a stockroom clerk can often double his effectiveness by bringing two packages to the window instead of one, and in doing so has not increased his effort more than, say, 10%. Obviously such an employee should not be given the full savings from increased labor efficiency but **a share of the savings.** Sharing plans with a factor F, proportionate to effort involved, are therefore most suitable to such indirect production jobs. Sharing plans are also safest unless true elements are standardized and synthesized.

The F is placed adjacent to the binomial (see below) in place of or multiplied with the usual fixed arithmetic fraction. The hourly rate may be omitted from the formula for group application, so that members may be given different rates. In that case, replace the word "Earning" with "Hours allowed." The omission of the hourly rate from the formula also allows combining a premium or factor sharing with a two-rate or step bonus arrangement without setting up two formulas, one for below and one for above task.

Choice of Incentive Method for Indirect Production.—One of the large electrical companies has recently made plans for the extension of extra-financial incentives to a wide variety of jobs not usually covered. As reported by Herbert Bisen, industrial engineer, the management recognizes nine methods of doing this and has appraised the methods according to immediacy, effectiveness, administrative cost, and clarity to

worker. These nine methods are listed below in descending order of the net appraised desirability. For any specific case this order may not hold.

1. Plans based on direct measurement of functions performed. (This is the synthetic task, always most reliable but sometimes too expensive.)
2. Plans based on records of net results obtained.
3. Plans based on reduction of personnel and payment for maintaining schedules.
4. Plans based on the ratio of direct to indirect hours.
5. Plan based on placing the indirect personnel in the groups they service.
6. Plan based on paying the indirect personnel the same earnings as the productive groups they service. (Similarly they may receive a bonus equal to some fixed per cent of the bonus earned by the direct producers.)
7. Plans based on evaluation of efficiency. (Preferably the efficiency of small specific groups but sometimes that of the whole plant.)
8. Plans based on percentage improvement over past performance.
9. Plans based on estimation of allowed time values.

In the management's judgment, the methods might oe applied as follows:

Method 1 might apply to: trucking, layout operators, shipping, storeroom, instructors, janitors, machine setters, and such maintenance work as that of carpenters, painters, pipefitters, structural steel workers, sheet-metal workers, laborers, bricklayers, wiremen, millwrights, and window-cleaners.

Method 2 might apply to: general maintenance, machine-setters, storeroom, and trucking.

Method 3 might apply to: storeroom, routine maintenance, and shipping.

Method 4 might apply to: routine maintenance (amount of such maintenance in relation to the amount of direct production to be determined by study and data plotted).

Method 5 might apply to: material handling.

Method 6 might apply to: tool crib.

Method 7 might apply to: machine-setters, instructors, storeroom, and boilerroom.

Method 8 might apply to: routine maintenance, oilers, instructors, and truckers.

Method 9 might apply to: general maintenance and toolroom.

APPLICATIONS TO STORING AND MATERIALS HANDLING.—Among the common kinds of indirect production to which wage incentive plans are readily applicable, the work of storing and of materials handling offer considerable opportunities for appreciable savings.

Examples of Stores or Stockroom Plan.—Westinghouse Electric & Manufacturing Co. (Trans. A.S.M.E., MAN-50-3) used such a plan with group application for many kinds of work, one of which was stores. Nine stock men constituted a group. In a certain pay period there were 96 working hours and the "Hours actual" was equivalent to 96 × 9, or 864 man-hr. Material for 700 control-panel sections was delivered to the floor by the storeroom group at an allowed time of 1.50 man-hr. per panel. The "Hours standard" were, therefore, equivalent to 700 × 1.50, or 1,050 man-hr. Using a factor F equal to .10 and substituting in the formula, without the rate, we have:

$$\text{Hours allowed} = 864 + .10\ (1{,}050 - 864) = 882.6$$

This figure was divided by 9 and multiplied by each man's higher rate. The application to toolroom work was similar.

The Real Silk Hosiery Co. used a special Baum plan, or multiple constant sharing plan for four classes of stockroom employees. (A.M.A. Prod. Exec. Ser. 23.) Primarily, premium depended upon volume of work, and the Halsey fraction of ½ was retained, but a deduction was also made for errors F_d. Ranges of volume were made high for this kind of work. For volume handled above task the base rate varied as follows:

From 0% to 33% net gain above task, rate = \$.40
From 33% to 50% net gain above task, rate = .44
From 50% on up, rate = .48

As in the Baum direct production plan, wages saved were shared (50–50) between employees and company. The net gain referred to above equals $\frac{(H_s - H_a) F_d}{2}$ which is a reduced Halsey sharing and was divided by H_a to find the per cent which in turn determines the rate.

$$\text{Earning} = \text{Time wages} + \text{Half time saved} \times \text{Deduction factor} \times \text{Rate per hour}$$

$$E = H_a R_h + \frac{(H_s - H_a)}{2} \cdot F_d \cdot R_h$$

where $F_d = 1.00 - \%$ deduction for errors as per empirical scale.

For instance, suppose the stockkeeper accomplished a 75-hr. task in 45 hr. with two errors. The scale deduction for two errors is 4%.

$$E = 45 \times \$.40 + \frac{(75 - 45)}{2} .96 \times \$.40 = \$23.76$$

With no errors, F_d would have been unity and the net gain term divided by H_a would have equaled 33⅓%, so that the second rate of 44 cents would have been earned and total wage would have been \$26.40.

Example of Materials Handling Plan.—The usual means of keeping this phase of management up to requirements is: (1) coordinated planning and scheduling, and (2) group bonus. Supervision of material handling is often difficult because of its interdepartmental nature. For this reason, all handling is sometimes centralized under a department control of its own. When this is done, it is less difficult to establish uniform standards and to hold everyone responsible for definite performances.

At the plant of Westinghouse Electric & Manufacturing Co., interdepartmental trucking is done on standardized routes and the drivers are rewarded in groups provided they exceed their task amount of trucking. Task is based on the number of packages handled as shown by a system of delivery stubs and the number of trips. Each of the call stations is assigned a number and provided with a time stamp. The task rate was set at about 11% above the guaranteed day rate. The calculation was as follows:

$$\text{Hours allowed} = H_a + .12\,(.066\,N - H_a)$$

where N = Number of packages handled for pay period
H_a = Hours actually worked by group for pay period
H_s = Hours standard = in this case .066 N
(The .066 is the hours per package.)

When the hours actual were down to, or less than, the hours standard, a higher rate was earned. In the particular case, $N = 400$. Since the required effort fluctuated somewhat, an additional factor allowing for such variation was used, .12 in this instance. Locomotive men were similarly treated. If they were handling loaded cars only, the formula simply provided for hours standard for such complete movement. If they were handling boxes and crates only, the formula became:

$$\text{Hours allowed} = H_a + F\,(.3\,N - H_a)$$

where F = Factor allowance or .10 in this instance (The .3 is the hours per box.)

Other groups were engaged in operating either flat or hoist trucks, the time of delivery for which was different. The N item was, therefore, broken down to take care of two classes of work as follows:

$$\text{Hours allowed} = H_a + .25\,(.46\,N_f + .317\,N_h - H_a)$$

where N_f = Number of deliveries made by flat truck (.46 hr. per delivery)

N_h = Number of deliveries made by hoist truck (.317 hr. per delivery)

These incentives resulted in better coordination of work to keep up full capacity, use of telephones to keep the dispatcher perfectly informed, and other manifestations of cooperation. Curves (Fig. 37) of unit cost and numbers of units handled in one of these cases show the distinct success of the incentive.

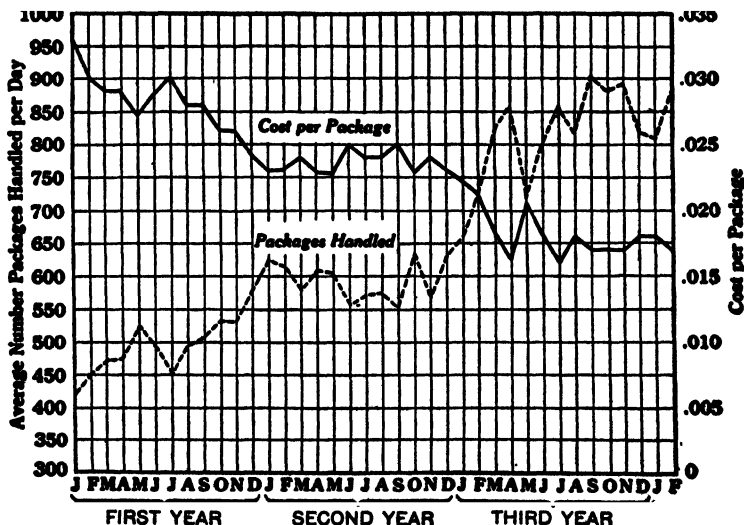



Fig. 37. Results of Incentive Plan for Factory Trucking

INCENTIVES FOR MAINTENANCE AND REPAIR OF EQUIPMENT.—An efficient maintenance department is most important to the success of incentives in production departments and can help increase task standards throughout a plant. Such a result is evident in continuous process manufacturing but is not always appreciated elsewhere. An incentive for maintenance and repair must be made **to encourage elimination of needless repair** as well as to expedite needed repair. The ideal condition would be for men of this department to spend all of their time on the preventive work of maintenance, thus eliminating breakdowns altogether. Allotment of definite maintenance responsibility to each man in this department is in itself effective and has been known to reduce volume of breakdown repair 66%, and at the same time reduce production delays 80%.

Two distinct practices are generally used. One practice is to assign certain individuals to definite machines and consider them as belonging to a group of direct producers. This plan is practical wherever direct producers are paid in groups and all that is needed is to arrange the share of group bonus which maintenance and repair men shall receive. Another practice is to centralize control of all maintenance and repair, establish a cost budget for this group, and arrange shares of relative savings. Neither of these practices fulfils the requirements. A slightly better way is to fix a route for each individual and if all equipment in that route comes through the month without delays award a bonus of, say, 25% of maintenance time wages. If delays have happened, deductions proportionate to the time of delay can be taken from the potential 25%. Obviously the nature and newness of the equipment affect the possibilities of this bonus and the reward cannot always be proportionate to the work or responsibility involved. Adjustments and supervision are necessary. The best way is to work out an itemized schedule of inspections and periodic overhaulings for the equipment of each route.

The problem of standards for general maintenance is discussed at length in Lytle's Wage Incentive Methods (rev. ed.). **Time standards** drawn from the best past experience should be included. On this foundation a sharing plan may be applied with both effect and safety. Major repairs may have to remain on time payment although these can eventually be included if records are adequately kept.

Example of Centralized Maintenance Plan.—Describing the incentives for the maintenance crew in the Hood Rubber Co., C. P. Flora said in part (S.I.E. Bul., vol. 13):

At that time we had about 400 mechanics to whom we considered that standards might be applied. To give prompt service on small repairs, while a centralized force remained available for large jobs, the factory had been divided into four maintenance areas, with a maintenance supervisor and a force of four to six mechanics assigned permanently to each area. This area contained one or more men of each of the trades most likely to be needed.

Besides these mixed area groups, we had the usual centralized groups of each of the trades, controlled by a foreman experienced in that trade. Our purpose was to cover with direct standards as large a part of our construction and maintenance work as seemed practical, and where direct incentives were not practical to use some form of indirect incentive.

Indirect incentives were first to be applied, because it seemed desirable to get effective results in our small job maintenance immediately. The first

department was electrical repair shop; then electrical construction, and following these, in order, pipefitters, millwrights, and finally carpenters and tinsmiths.

The pipefitting application probably illustrates as many of the peculiarities as any of the applications. The first procedure was to make a tentative list of all possible operations connected with steam-fitting work. This list, corrected as our studies proceeded, formed a basis for analysis of time studies. The number of possible items listed is nearly 200, yet even with this large number, each item represents a complete operation rather than an elemental operation.

Time studies were taken, and when sufficient in number were calculated to normal actual times and plotted. This facilitated interpolation for sizes of pipe on which we had not been able to obtain actual time studies. Many curves of this kind were obtained. To simplify calculations, composites were obtained by the addition of the elemental curves. These formed a basis for tabulations of constants from which standards are made up. In general, combinations are made in such a manner that the only data required when reporting a job are the number of feet of pipe and the number and kind of fittings. Data are simplified as to questions of screwed or flanged fittings and a count of the number of "ways": for example, an elbow counts as two ways, a tee as three, a union as three, and so on.

We also have removal standards, from which are eliminated elements not present in removal operations as they differ from construction work, while adjustments are made for elemental operations that are simplified. Since construction standards are usually based on a pipefitter working with a helper, we have an adjustment for a man working without a helper based on the time that can be saved by the correction of losses caused by the uneven balance of labor between the two.

These direct standards were applicable to 53% of the work, in a typical week. A small proportion of jobs, amounting to 3% in the week mentioned, are too difficult or too small to justify computing of a direct measure. A man is paid at the average rate that he has earned on his directly measured work over previous four weeks.

Besides these larger jobs are a multitude of small jobs originating in the maintenance areas. In some of the trades, and it is probably true of the pipefitting shop, clerical work of recording and computing standard times and workman's efficiency on jobs of less than an hour and a half costs more than can possibly be saved through operation of direct incentives. Consequently, we did not apply direct measures to small area jobs, but used an indirect method. In maintenance areas, the area mechanics are considered as a group: the group is, however, too small to take care of all of the small repairs in an area; consequently, assistance must be obtained from the central shops. The purpose was to give members of the group an incentive to do as much as they could without drawing upon the central force; to give members of the central force when out in an area an incentive to cooperate with the area men; and to do all this without setting up an elaborate control mechanism.

The formula for computing the area incentives is based on the product of a few simple ratios, and of a rate of working obtained by the actual time study of the area mechanics. The ratios are the standard hours of maintenance work to the actual hours; the value of the machines in operation to the total value of those in the area; and actual production of area to production during the standard period.

$$\frac{\text{Standard hours of maintenance work}}{\text{Actual hours of maintenance work}} \times \frac{\text{Value of machinery operating}}{\text{Value of machinery in area}}$$

$$\times \frac{\text{Actual production} \times \text{Standard point hour}}{\text{Standard production}} = \text{Weekly point hour of area}$$

The efficiency of the area mechanics was determined by actual time study for a period of a week. A time study observer was assigned to each area mechanic and recorded everything that he did for a week. From these observations, after eliminating all work that had been performed by the mechanics merely to appear busy, a standard efficiency was set up for the area, which multiplied by the ratios mentioned, gives a fair measure of efficiency of the area mechanics. Shops on direct standards average 20% above standard, and the men on indirect measure average 9% above standard, an increase of 60% above their earlier efficiency.

A summary for a typical week showed, as compared with the original basis for work directly measured, an increase of 15% in the average earnings of the mechanics and a saving of 27.5% in cost of maintenance labor. For work measured indirectly, the figures are 5% increased earnings and about the same relative savings. For whole group record is 12% more to the men, and savings of about 27%.

Example of Tool- and Die-Making Plan.—Products which are rarely made twice alike are said to involve too much of the unknown to permit of standardization. They are certainly difficult to standardize. On the other hand, cost of tools, dies, etc., must be estimated within reasonable limits. A certain amount of analysis and measuring is, therefore, not only possible but unavoidable. Usually by a little extra pains this estimating can be made virtually a standardization. In other words, an accumulation of data on definite elements and a practical speculation of the "unknown" will make a standard which can be used for incentives as well as for more accurate cost and working plans.

Most toolrooms can be handled better by group than by individual application, due to the necessity of utilizing the law of compensating errors to get a reasonable amount of accuracy.

The work required to manufacture some tools and dies can be estimated closely enough to make individual incentive feasible. This is particularly true on repetition work and on simple tools and dies where very little development work is necessary. The individual job estimates, however, will have errors between 0 and ±20%. It is easy to see how unsatisfactory this is for individual incentive operation. Any one man's work up to 10 dies can be averaged and get the necessary accuracy, but this would cover such a long period that the reward would be too far off to be effective. Several concerns have grouped toolroom operators with results far beyond anything that could be expected on daywork.

Westinghouse Electric & Manufacturing Co. extended incentives to the making of dies (Am. Mach., vol. 75) and tools (Am. Mach., vol. 69). Writing on the former of these applications, Clark says in part:

It should be kept in mind that the success of the application hinges largely on the breakdown for time values, the basis for this being the tool drawing in as complete form as possible. . . . The time study group, working from this tool sketch, breaks down the labor content of the die and applies the time values. These time values once applied, may not be changed except by the issuance of a special work order controlled by the shop supervisor. . . . Time values for material cutting have been established for that labor, and the storeroom cuts the material, collects the standard die parts and accessories, and forwards them to the machine or the building section.

The building section builds the die. It may also be called assembly or fitting. No machine work is done in this section. The building is done by a group of four to ten men. There may be as many groups in a building section as needed. Time study has set a time value for the building of the die in the building section. The die is built by the process of assembling or

fitting the various parts coming from the machines and the storeroom according to the specifications contained in the tool sketch. This, and the workmanship, should be subject to rigid inspection.

After building inspection, the die goes to "test and try-out." This consists of setting the die in the press for the first time and making a trial for sample. The time value for this step of the work may be applied from an established schedule based on the size and type of die.

INCENTIVES FOR WINDOW WASHING AND JANITOR WORK.—Cleaning and other janitor work is sometimes controlled by separate departments and sometimes it is centralized as a branch of maintenance. In the former case, that part of it related to production, such as removing waste from machines, may be related to a production group and allowed to share in the group incentive. More often, it must be treated separately. If it is not centralized, no one thinks it sufficiently important to check. If it is centralized, it is a simple matter to establish time standards per window pane of given size, per unit floor or wall area, etc. There may also be a relation between some of this work and departmental efficiency. When such a relationship exists, standards, instructions, and bonuses will be particularly worth the trouble. In large organizations, much of this work will usually be functionalized and graded, partly to allow use of various job titles and rates. If properly done, the grading will minimize the amount of servility which tends to accompany the lower types of janitor work.

The psychology of this grading is as important here as anywhere else. Paying by the number of **standard hours accomplished,** regardless of actual time, is one of the most effective incentives and simple enough for any unschooled man to comprehend. One company cites a case of a cleaning job which cost $16 under this plan and $106 previously under day wages. Lowry has set tasks for many such jobs.

INCENTIVES FOR INSPECTION.—If there is any kind of work in a factory which may seem too sacred for financial incentives, it is inspection work. Yet certain kinds of inspection have been timed and given bonuses since the later days of Taylor. At first this practice covered only mass work such as inspection of balls for ball bearings where little judgment was involved. As mass production spread, it was found that for many products inspection time bore a definite relation to direct production time. It has become evident, therefore, that tasks can be established and bonuses paid for inspection wherever the scale of production is large, that is, where inspection is carried on much as other operations. It may, however, require a super-inspection by one not paid any bonus.

Example of Inspection Incentive.—The Edison Electric Appliance Co. (A.M.A. Prod. Exec. Ser. 22) determined this ratio from past records, reduced allowed time 45% from this value and paid a 1% bonus for every 1% reduction below allowed time. In other words, it put inspection on piece rate. As a quality bonus, in the negative, may deduct from piece rate, so "rework" cost was deducted from 100% earnings saved. Quality standards were especially stressed. Passing of defective work was caught by subsequent operators except for final assembly. In that case it was necessary to use two "over-inspectors." Even the last-named operators were paid a bonus on the number of errors detected and the

errors were charged back on the employees responsible. Frequently, random inspection was sufficient for over-inspection as it was, in fact, for many interoperation inspections also. These bonuses were usually allotted by groups and paid monthly. The main prerequisite for any inspection bonus is a complete set of standards for quality (see also Incentives for Quality and Waste, in this Section).

GROUP TASK EXPRESSED IN TERMS OF BUDGETED EXPENSE.—Where it seems impractical to determine tasks in terms of production units, it is possible to secure a rough equivalent in terms of expense. Actual expense of the operations over a period of at least 10 years is used as a guide and an amount in dollars is budgeted which is a little under that of the best previous year. This amount of expense is set up as a bogie and used as a group or departmental task. Bonuses are arranged in advance, usually in some per cent of savings relative to the bogie. As this per cent of saving or factor is determined for each group, the individual prorated share of it is increased whenever there is a reduction of numbers in group.

Example of Group Task.—Newport News Shipbuilding & Dry Dock Co. began applying this plan to their material transfer group and stores-keeping group. Over a 10 months' period the gross savings on the bogie for a material transfer group was $28,000, and bonuses paid amounted to $7,000, leaving a net saving of $21,000. In the storeskeeping group, gross savings were $9,000 and bonuses paid amounted to $2,000, leaving a net saving of $7,000. A later check of all departments on this plan showed that the grand total gross earnings were $55,000, and the bonuses paid amounted to $15,000, so that the net gain to the company was $40,000.

POSSIBILITIES FOR INDIRECT PRODUCTION PLANS.—Westinghouse Electric & Manufacturing Co., which has carried incentives through to drafting (Trans. A.S.M.E., MAN–54–2), claims that it has saved on indirect production as follows: 20% in concreting and hand painting, 25% in carpentering and pipe covering, 30% in laboring, roofing, pipefitting, and sheet metal working, 35% in structural steel working, 40% in spray painting and shop wiring, and 45% in janitoring. Thorough job standards were established for all.

Financial Incentive Plans for Supervisors and Executives

COST SAVING VS. PROFIT SHARING.—All incentive plans for supervisors and executives are based directly or indirectly on either savings in operating costs or on final over-all profits, rarely on both. The first type of plan uses measurable and gradable accomplishments, out of which a compound task is established and rewards are derived from relative operating savings, usually shared with the company. The second type uses profits, as they may occur, or a budgeted amount of profits, for task and rewards derived from a fund which is held back from declared profits. Two conclusions are obvious: (1) that the first type can reward proportionally to effort, and the second type cannot, that is, profits do not vary directly with human effort; (2) that the first type is preferable

for all but the highest executives and is not inapplicable to them, and the second type is suitable only to those who can take a long view and can influence the company in a major way. Between minor foreman and president there is a debatable zone but this zone is not far below the president. Jordan (N.A.C.A. Bul., vol. 11) suggested that a works manager might well draw one-third of his bonus from a profit sharing fund, and two-thirds from savings.

COST SAVING PLANS FOR SUPERVISORS.—The most direct and simple incentive plan for supervisors is that which uses a budget of direct labor plus expense cost per unit of output for task and provides percentage rewards for reductions in these costs relative to that budget. The percentage should be suited to the volume so that the bonus for satisfactory results would be around one-fifth of the salary. As in other cases of cost standard, the weakness lies in the inclusive nature of total costs. This weakness might be corrected by the use of several more specific costs but it is even better to go back of costs. This procedure requires the establishment of a **compound task** which will include about three of the most important measurable factors such as volume, material waste, and punctuality of deliveries, plus one gradable factor such as interdepartmental cooperation. A factor such as departmental "housekeeping" might be used temporarily. Choice of these factors depends on desired emphasis. All factors must be weighted to suit the desired emphasis and to bring mutually satisfactory quantities. Graded factors are subject to challenge and should never carry more than 20% of total weight. The period for computation and payment should be short enough to make the connection clear between cause and effect, usually a month, but preferably a week. Although overlapping, total cost is sometimes included as a measurable factor.

GENERAL REQUIREMENTS FOR A SUPERVISOR'S PLAN.—

1. The plan should be guaranteed a year ahead and not changed merely because a good supervisor makes more than is expected.
2. Results should be measured or graded and the bonus paid in separate envelopes as frequently as convenient. The bonuses should start at about 15% of salary and advance in proportion to responsibility to at least 30%.
3. The bonus must encourage the steadying but not necessarily the increasing of production, waste and cost reduction, maintenance of quality, utilization of equipment, and assistance to employees.
4. The bonus must not oppose: change in method or rate, transfer, and interdepartmental accommodation.
5. Operation must be fairly simple so that it can be figured with little expense and can be clearly demonstrated.

PROFIT-SHARING PLAN FOR EXECUTIVES.—The plan of sharing profits with executives was used widely in this country from 1921 to 1929 and gave sensational results in more than one case. It consists essentially in the establishment of a bonus fund which is usually some prearranged portion of final over-all profits remaining after all charges, except federal taxes, have been deducted from income. **Division of the fund** among the executives is usually made arbitrarily, and all too often secretly, by the president or by a small committee appointed by him. Grades of sharing may be fixed but eligibility to grades is left to some-

one's judgment of each individual's contribution to, or responsibility for, company success. Payments may be made in all stock, all cash, or part each.

High executives who must stand or fall with long-run profits usually prefer this speculative plan of profit sharing to any surer but less potential plan. Since such executives have a comprehension of the business as a whole and are in position to affect it as a whole, plan of reward is reasonable if not ideal. Aside from risk of lean years which most executives can well take, the only danger in executive profit sharing is that it may run counter to the interests of stockholders. This danger does not go beyond psychological friction if awards are made contingent on certain prerequisites. If these prerequisites include more than predetermined amounts of surplus profits, however, the plan shifts from pure profit sharing to part, or all, cost saving.

COST SHARING PLAN FOR EXECUTIVES.—If a company intends to offer a big incentive contingent on a big achievement, the policy is usually to make salary low, merely enough to provide a proper standard of living, say $12,000 for a president. It then budgets either volume or total cost and scales percentage bonuses for varying increments of volume or reductions of total cost. Occasionally both are used and weighted.

Of the **savings relative to budget** which have been created, a portion is automatically payable to the bonus fund and the fund is automatically divided among executives according to prearranged percentages. If the company is expanding rapidly, payments are likely to be made in stock but more often the amount due each individual is credited to him and disbursed in 12 monthly check payments.

COMBINATION PLAN FOR EXECUTIVES.—If a table is made between two percentage scales, one a percentage of the gross profit budget and the other a percentage of the total expense budget, then bonus figures may be planned for all **combinations of profit and cost** between these coordinates. The (100, 100) square or desired combination task would be the starting place when designing such a plan. In the example of Fig. 38, designed by Bigelow, for sales executives but applicable in principle to any other high executive (see Oil, Paint and Drug Reporter, vol. 121), the bonus for the (100, 100) square is 25%. The highest possible bonus of 35% is then located at the (105, 95) square, that is 105% profit and 95% cost, and zero bonus is located at the (90, 120) square. All other squares are filled in as may seem equitable. Such a plan prearranges suitable bonuses for all combinations of the two major variables, profit and cost. It avoids all other weighting of factors, and is therefore simple in the extreme.

REQUIREMENTS FOR AN EFFECTIVE PLAN.—From a well-made survey (Fact. Mgt. & Maint., vol. 80) of over 300 companies, Poole recommends the following principles:

"1. The executive should be able to earn from 35% to 65% extra compensation through the plan.
2. Such payments should not total more than one-third of the resultant saving.
3. At least 20% of the factors used as a basis of payment should be 'plant as a whole,' rather than departmental factors.

4. The factors themselves and their relative weighting should be determined separately for each individual position.
5. The departmental factors must be directly controllable by the individual affected, and the 'plant as a whole' factors by a group of similarly ranking individuals."

% OF SALES EXPENSE BUDGET	% BUDGET OF GROSS PROFIT															
	105	104	103	102	101	100	99	98	97	98	95	94	93	92	91	90
95	35.0	34.0	33.0	320	310	300	27.5	250	22.5	20.0	175	150	12.5	10.0	7.5	50
96	340	330	32.0	309	299	289	26.5	241	21.7	193	169	144	120	96	7.2	48
97	330	319	309	298	28.8	27.7	25.4	231	208	18.5	162	138	115	92	69	46
98	320	31.0	29.9	289	278	268	246	22.3	201	17.8	156	134	111	89	66	44
99	310	300	29.0	279	269	259	237	216	194	172	151	129	107	85	64	42
100	30.0	290	28.0	270	26.0	250	229	208	187	166	145	124	103	82	6.1	40
101	29.0	280	270	260	25.1	241	221	200	180	16.0	139	119	99	79	5.8	3.8
102	280	27.0	26.1	25.1	24.1	232	212	19.3	173	154	134	11.4	95	75	56	3.6
103	270	26.0	25.1	241	23.2	22.3	204	18.5	166	147	128	11.0	9.1	72	5.3	34
104	26.0	25.1	241	232	223	213	195	17.7	159	141	122	10.4	86	68	5.0	32
105	250	241	23.2	222	213	204	18.7	169	15.2	13.4	117	99	82	65	47	30
106	240	231	222	213	20.4	195	178	162	145	128	111	95	78	61	45	2.8
107	230	221	212	203	194	186	170	154	138	122	106	90	74	58	42	26
108	220	21.1	20.3	194	18.5	17.7	162	146	131	11.6	10.0	8.5	7.0	5.5	3.9	2.4
109	210	201	193	184	176	168	153	139	124	110	95	80	66	5.1	3.7	22
110	200	192	184	175	166	158	144	130	117	103	89	7.5	6.1	48	3.4	2.0
111	190	18.2	174	16.5	157	149	136	12.3	110	9.7	8.3	70	5.7	44	31	18
112	180	17.2	16.4	15.6	148	140	128	11.5	103	90	7.8	66	5.3	4.1	28	1.6
113	170	162	155	146	138	131	119	108	9.6	84	72	61	4.9	37	26	14
114	160	152	145	137	129	122	111	100	8.9	7.8	6.7	5.6	45	34	23	1.2
115	150	142	135	127	120	113	103	92	82	72	61	5.1	41	31	20	10
116	140	132	126	118	110	104	94	85	75	66	5.6	46	3.7	27	18	08
117	130	12.3	116	109	101	94	85	76	68	5.9	5.0	41	32	24	15	06
118	12.0	113	106	99	92	85	7.7	6.9	6.1	5.3	4.4	3.6	28	20	1.2	04
119	110	103	97	90	82	76	69	61	5.4	46	3.9	32	24	1.7	09	0.2
120	100	93	87	8.0	73	67	6.0	5.3	47	40	33	2.7	20	1.3	0.7	0

STANDARD % OF SALES EXPENSE BUDGET

STANDARD % BUDGET OF GROSS PROFIT

FIG. 38. Bonus Table for Executives, Combination Plan

Nonfinancial Incentives

APPEAL TO CREATIVE INSTINCT.—The term nonfinancial incentive is self-defining in that it embraces all incentives to increased effort other than the financial incentives. Wolf, who first used the term to describe his method of stimulating improvements in the paper pulp industry (Trans. A.S.M.E., vol. 40; see also M.E., vol. 45), claims that appeals to the creative instinct are more fundamental than appeals to

the acquisitive instinct and that by using the former appeals industry can dispense entirely with the latter appeals. In the particular development cited, there were no financial incentives other than time rates and an annual readjustment of the same. In fact, this adjustment was largely between skill classifications. Individual variation in a single skill class was eliminated by all operators coming up to par in output. Additional gains and other successes achieved were due, therefore, entirely to nonfinancial incentives.

OPERATION JOINTLY IMPROVED AND STANDARDIZED.—The basis of appeal to creative instinct is education. Requirements of customer and management are taken back to the employees. The solution may or may not be known but the employee is taken into management's confidence and the two parties undertake to find the solution jointly. Starting from the finishing operation, each difficulty is traced back through previous operations until causes of trouble are found and correct procedures discovered. Correct procedures are then standardized by the engineers, charted for all operations and charts given to operators as guides. In pulp cooking the chart displayed three paths of concurrent performance between time and pressure and operators were given the responsibility of adhering closely to them.

INDIVIDUAL PRODUCTION RECORDS POSTED.—Performances of departments, related groups, and of separately working individuals are posted either for the previous day or, where processes last more than a single day, for the last run. As far as feasible these records are broken into three components: quantity, quality, and economy. Furthermore, the immediate record may be compared with: (a) ideal performance, (b) best that has been achieved, and (c) best the particular party has achieved. By this means operators become interested in their showings, reputations, etc., and look upon their jobs as competitions of skill. There is no doubt that this practice puts pride as well as intelligent cooperation into individuals. It has been equally successful with skilled and unskilled, with organized and unorganized men. In short, it is psychologically sound for any kind of human beings.

PRACTICAL ASPECTS.—The clerical work of Wolf's method is extensive but much of it in payroll computation is eliminated and some of the work of industrial engineering is eliminated. Where it is impractical to keep records on the several phases of performance, inclusive cost figure may be used instead. In any case complete costs should be given department heads and Wolf found it worth while to prepare such figures for indirect producers. For instance, the maintenance gang was given a statement of all material and labor costs incurred each previous day. The men had had little concept of the value of materials and, when the figures were given them, became thoroughly interested in improving economy. However inapplicable the elaborate performance curves may be in many industries, the better use of cost information is suitable to any industry. Educational presentation and partnership treatment is all that is necessary to make cost data into effective nonfinancial incentives. On the other hand, it takes a great deal of skill on the part of management to make nonfinancial incentives a major influence. Personality is all important. Under ordinary circumstances a management will do well to utilize nonfinancial incentives as supporting measures to

financial incentives. There need be no conflict between them. Either can be emphasized according to the kind of work and the particular kind of employee.

THREE-POSITION PLAN OF PROMOTION.—The three-position plan of promotion was suggested by Frank B. Gilbreth (Annals of Am. Academy of Political and Social Science, vol. 65). It considers each man as occupying three positions at a given time, one above him, for which he is studying, one he is doing, and one below him in which he is training his successor. This series of three is made progressive by a **master promotion chart** which consists of a diagram of all positions in the organization arranged in lines of most likely advancement. In this way the official in charge of promotion is able to visualize the complete problem of training and advancing employees. The plan attempts to abolish the "blind-alley" tendency and to move up all workers eventually, excepting those who choose to remain on the job for which they are peculiarly fitted. Such a specific plan may not always be feasible but a constructive policy for promotion is always desirable. For an example of this practice see Bergen, Developing Promotional Opportunities (A.M.A., Personnel, vol. 15).

SECTION 19

PLANT MAINTENANCE

CONTENTS

PAGE

Long-Term Planning

Tools, Equipment, and Materials

Maintenance Methods

Lubrication of Equipment

PAGE

Good Housekeeping

Depreciation of Buildings and Equipment

Depreciation Bases

Apportioning Depreciation

SECTION 19

PLANT MAINTENANCE

PURPOSE OF MAINTENANCE.—The task of maintenance is to keep buildings and grounds, service equipment and production machinery, in satisfactory condition, according to standards set by management. The work assigned to the maintenance department usually includes removals and installations of equipment. In cases where new construction and alterations are added to the duties, care should be taken to keep separate records, because such work on either building or equipment is beyond the limit of maintenance and becomes capital expenditure.

WORK OF THE MAINTENANCE DEPARTMENT.—In small plants maintenance activities are combined with the work of other departments, such as engineering department, production department, or plant engineering. In large plants the work is organized separately, with an executive in charge who reports directly to a works manager or plant superintendent. A term commonly used to designate the maintenance function in its broad sense is "plant engineering"; this term is used extensively in this Section. Fig. 1 gives the results of a survey made by Factory Management & Maintenance and indicates place of plant engineering department in different plants, work done, and to whom the executive in charge reports.

THE PLANT ENGINEER.—Fig. 1 shows that the typical organization provides for a **plant engineer,** whose range of work is indicated in the accompanying tabulation, Fig. 2. Under modern conditions, continuous introduction of improved service equipment, new operating methods and machinery add continuously to the tasks of maintenance. Selection of manufacturing equipment is primarily the concern of production engineering, but the plant engineer will often be consulted about installation, power and service requirements, and specifications affecting maintenance. Minimum maintenance costs require sound engineering all the way from the proper selection and arrangement of equipment to the development of efficient tools and methods in maintenance work. With such a broad field to cover, the plant engineer needs wide technical knowledge and must also be a good executive.

IMPORTANCE OF PREPLANNED MAINTENANCE.—Trend toward modern practice of organizing maintenance work to prevent interruptions of operations is the outgrowth of several factors:

1. **Increased mechanization, while decreasing direct labor costs per output unit, has required at least a portion of the gain to be spent on maintenance of the equipment. Maintenance work has grown to**

Size of Plant	Individual in Charge of Plant Engineering Function		Kind of Work Included as Part of Plant Engineering Function
No. of Employees Motor Hp.	Title	Reports to	
15,000 18,000	Plant Engineer	Factory Manager	Electrical, mechanical, and building maintenance.
7,700 11,512	Maintenance Engineer	Plant Superintendent	Electrical, plumbing, millwrighting, plant inspection, outside and landscaping, factory layout, powerhouse, construction.
4,200 4,650	Plant Engineer	Factory Manager	Maintenance (electrical, carpentry, pipefitting, painting, millwrighting, tinsmithing, janitor service).
2,100 9,000	Chief Mechanical Engineer	General Works Manager	Plant electrical engineering, plant mechanical engineering, both including maint.
2,000 1,600	Maintenance Superintendent	Vice-Pres. in Charge of Mfr., who is also Works Mgr.	Millwrighting, carpentry, electrical.
1,500 315	Plant Engineer	Factory Manager	Mechanical maintenance, electrical maintenance, carpentry.
800 1,500	Master Mechanic	Assistant Superintendent	Mechanical and electrical maintenance.
800 750	Master Mechanic	Works Manager	Electrical and mechanical maintenance, plumbing, carpentry, millwrighting, painting, janitor service.
800 650	Buildings Supt., Chief Electrician, Machinery Maint. Supt.	Chief Engineer or General Superintendent (according to kind of work)	Buildings superintendence and maintenance. Plant electrical engineering. Machine repair and other mechanical maintenance.
600 7,000	Plant Engineer	Plant Superintendent	Plant electrical engineering, power plant, safety, maintenance, pipefitting, carpentry, machine shop.
600 900	Maint. Foreman, Mechanical and Machine; Mtce. Foreman, Elec.	General Superintendent	Mechanical and building maintenance, electrical maintenance, millwrighting, carpentry.
560 1,000	Plant Engineer	Chief Engineer	Electrical maintenance, mechanical maintenance, millwrighting, carpentry, painting, pipefitting, masonry, janitor service.
550 2,000	Chief Engineer	Plant Superintendent	Master mechanic's duties, maintenance foreman's and electrical foreman's duties.
300 1,650	Plant Engineer, who is also Mechanical and Division Supt.	Factory Manager	Consulting engineer's duties, chief electrician's duties, carpentry, yard labor, plant protection, painting, mach. shop, steamfitting, tinsm'g.
160 3,500	Plant Engineer, Master Mechanic	President, Superintendent, Plant Eng.	Chief engineer's duties. Chief electrician's duties. Master mechanic's duties.

FIG. 1. Plant Engineering Functions in 15 Plants

1. Building Construction and Maintenance

a. Masonry—foundations, walls, permanent partitions, plastering, tiling
b. Steel work—columns, beams, stairways, windows, fire-escapes
c. Floors—concrete, plank, wood block, mastic, steel plate or gratings
d. Service mains—water, gas, steam, compressed air, oil, piping for solutions used in production
e. Heating, ventilating, air conditioning —piping, ducts, radiators
f. Carpentry and wood construction
g. Painting
h. Plumbing
i. Roofing and tinning, cleaning
j. General building upkeep—hardware, glazing
k. Minor construction. (In large plants, sometimes major construction is carried on.)
l. Inspection of construction done by outside contractors

2. Mechanical Equipment Maintenance

a. Steam power equipment
b. Steam-heating, ventilating, and air-conditioning equipment
c. Millwright work—shafting, pulleys, drives, equipment installation, moving, set-up, alignment, removal
d. Compressed air equipment
e. Heat-treating and furnace equipment
f. Machine and operating equipment installation and repairs
g. Lubrication of machinery and equipment
h. Sheet-metal and welding work for maintenance or special construction
i. Material handling equipment
j. Storeroom equipment set-up
k. In some cases, factory layout—at any rate carrying out relayout plans
l. Mechanical meters, gages, recording devices, and instruments

3. Electrical Equipment Maintenance

a. Electrical power plant equipment, transformers, etc.
b. Wiring, conduits, switch boxes, cut-outs, power outlets
c. Electric lighting
d. Motors—rewinding, commutator repairs, etc.

3. Electrical Equipment Maintenance (*Cont'd*)

e. Alarm, signaling, call, and communication systems
f. Private telephone systems
g. Electrical equipment, tools, furnaces, etc.
h. Lightning protection devices
i. Electronic control
j. Electric meters, and instruments, gages, recording devices
k. Battery charging

4. Plant Safety, Fire and Theft Protection, and Other Services

a. Safety guards and all safety installations
b. Floor marking in plant, road marking, and walkways outdoors
c. Warning signs
d. Railroad and roadway crossing protection
e. Watchmen's service—fire, burglary, etc. (Plant protection in wartime was placed under works manager or other executive.)
f. Fire-fighting equipment—yard hydrants, sprinkler systems, trucks, ladders, axes and other tools, hose, lanterns, pails, extinguishers
g. Janitor services and general cleanliness
h. General plant housekeeping and clean-up

5. Yard and Ground Maintenance

a. Railroad tracks, switches, trestles, etc.
b. Roadways, walkways, paving, concreting
c. Tunnels and conduits
d. Sheds and other yard structures
e. Outdoor crane structures
f. Poles for cables, wiring, etc.
g. Fences
h. Outdoor signs
i. Rigging
j. General yard layout
k. Outdoor storage areas and facilities
l. Landscaping and gardening—lawns, trees, shrubbery
m. Parking facilities
n. Yard drainage
o. General yard cleanliness and good housekeeping
p. Collection and disposal of refuse, rubbish, ashes, etc.
q. Snow removal, road sanding

In all cases this work includes maintenance inspections, and adjustments, repairs, replacements, and the operation of shops for various kinds of work.

Fig. 2. Functions of Plant Engineering

the point where costs of labor and material warrant more detailed study and control. It has been found uneconomical to retain large maintenance staffs for emergencies which planning and systematized inspection can avoid.

2. **Close management of production,** with minimum stocks between operations or direct flow from one machine to the next, has made interruptions to production more costly. Even where workers are paid on an output basis, regulations often prescribe payment for waiting time when workers are held on the job waiting for work. Lost profits from production stoppage frequently exceed the cost of idle labor.
3. **Failure to deliver on time,** with serious consequences and possible loss of business, may result from interruptions to operations.
4. **Correction of defective conditions** not only decreases cost of repairs but maintains performance efficiency of machinery as to quantity and quality.
5. **Service expenses** for steam, electricity, air, water, etc., are often reduced by continuous maintenance.
6. **Specialization of maintenance work,** within reasonable limits, results in increased reliability of work done and lower over-all cost.
7. **Planning of maintenance operations** will insure needed spare parts being on hand in stores without excessive accumulation of obsolescent material.

The principal objective of maintenance is, therefore, to anticipate and prevent interruptions in operation and keep equipment in condition for high efficiency performance.

Maintenance Department Organization

NEED FOR ORGANIZATION.—To achieve the above objective at reasonable cost, a certain amount of formal organization is essential. The following condition is frequently encountered:

In a new plant, once construction is completed, there is a period during which maintenance work is limited to minor routine matters and various adjustments. Unless the plant engineer has had previous experience in similar production, no clear pattern of maintenance work will stand out and work arrangements will tend to settle on the basis of meeting each need or emergency as it arises. After operations have been carried on in this manner for some time, the impact of wide daily variety will give the impression that the range of work and variations in conditions are beyond the possibility of standardization and planning.

This impression, however, has been found by engineers versed in organizing maintenance work to be largely illusory. It is true that the kind of tasks occurring are highly variable from day to day. Hence, the organization must be kept flexible. No ready-made system can be imposed on the individual plant because development of methods and procedure is a gradual process to be adapted to particular requirements. Despite great variation of detail, however, certain **general principles** can be outlined, relating to:

1. Size and control of working maintenance force.
2. Planning of work on long-term basis.
3. Daily issuance of work orders.
4. Standard practice instructions.

5. Storing of spare parts and tools used for repairs.
6. Inspection methods and schedules.
7. Maintenance records.

These factors of successful maintenance are discussed below.

SIZE OF MAINTENANCE FORCE.—A primary requisite for adequate maintenance is sufficient men—but not an excessive number—of each craft to meet the demands under peak loads. It is unwise to budget too closely, but in the interest of plant discipline as well as economy, excessive personnel should be avoided. Where peak loads can be foreseen but the nature of the jobs prevents spreading work over a suitably long period, temporary shifting of men from production to maintenance may remove the need for carrying a large maintenance crew. Where maintenance work has not been set up on an organization basis, past history is an unreliable guide; frequently, unnecessarily large crews have been retained. On the other hand, an aging plant may require an increase in the crew to avoid the danger of undermaintenance. A satisfactory solution of the problem requires a **man-hour rating of the work and an annual program of jobs**, as discussed later under planning of maintenance activities. Many jobs recur only at long intervals; hence the accumulation of adequate data may take a year or more. As an initial guide in setting up the maintenance force, a general overall ratio to determine the proper number of workers may help, but such a ratio must be used with caution.

RATIO OF MAINTENANCE FORCES TO PLANT FORCES.—G. I. Ross furnishes the data in Fig. 3, figures in last column having been added to show the comparison with a continuous process industry. Republic Steel, with much heavy equipment in continuous use, stated that 20% of its total force was used for maintenance. As equipment units become larger, heavier and more intricate, the proportion of maintenance workers increases, but the claim is made that, in a given type of manufacturing, approximately equal ratios are found in well-managed plants. Where the ratio is heavier than normal for the particular type of industry, the figures suggest there may be faulty organization, inadequate supervision or inspection, lack of a maintenance order system and records, or inadequate budgetary control.

A breakdown by crafts is useful in adjusting the maintenance force to the annual level of activity. **Comparisons between plants,** even when the product is similar, should be made with caution.

For example, in judging groups J and L in Fig. 3, where the pattern is fairly constant, managements prescribe varying degrees of cleanliness and plant protection. A food concern welcoming many visitors may have a modernistic building in a landscaped setting, with the advertising value justifying somewhat large expenditures for groundsmen, floor-polishers, painters, and other workers, far beyond any reasonable necessities of manufacturing. Location has a bearing. Northern plants with yards, sidings, and roadways have heavier snow removal expense. Plants in open areas have added yard expenses for the parking and protection of employees' cars.

Mechanical crafts items are so peculiar to each plant that general ratios must be used warily. For example, in garment-making one

Classification of Work	4 Fabric-Working Plants	5 Metal-Working Plants—Light Assembly	10 Metal-Working Plants—Small Products	12 Metal-Working Plants—Medium to Heavy	Average 27 Metal-Working Plants	1 Oil Refinery
A. Maintenance supervision and clerical...	.15	.30	.48	.41	.44	2.32
B. Belt repairmen, oilers, millwrights.....	.29	.50	.75	1.27	.96	–
C. Blacksmiths, welders, hardeners, ironworkers..........	.02	.15	.17	.14	.16	2.32
D. Electricians, motorwinders...	.10	.50	.64	.58	.60	1.16
E. Machinists and all machine fixers.......	.46	.30	.98	1.63	1.22	1.74
F. Carpenter on maintenance work, patternmaker on maintenance woik...	.10	.35	.48	.39	.43	1.16
G. Painters, glaziers..................	.04	–	.16	.12	.13	1.74
H. Masons, plumbers, pipefitters, tinsmiths.	.12	.20	.71	.68	.66	7.55
I. Truck repairmen................	.03	–	.01	.12	.06	–
J. Janitors, porters, sweepers..........	1.10	1.31	.80	1.64	1.20	1.16
K. Watchmen, roundsmen, plant policemen*	.31	.66	.63	.71	.66	1.16*
L. Yardmen, clean-up men, general maintenance laborers, miscellaneous...	.24	.35	.66	.54	.59	4.64
Total............................	2.96	4.64	6.47	8.23	7.11	24.95

* Exclusive of wartime police.

Total plant force includes all personnel in manufacturing activities, but excludes nonmanufacturing, such as audit, sales, general accounting, advertising, and billing.

FIG. 3. Percentage of Maintenance Workers to Total Plant Force

machinist may readily manage current adjustments of machines used by total force of 200, providing spare machines are available to send out to a service shop for major repairs. A large garment factory, however, with its own repair shop, would show a higher maintenance ratio.

The general conclusion is that where the plant engineer has reliable data from closely comparable plants with which he is familiar, such existing satisfactory **ratios can be of assistance** in establishing the proper size of maintenance crews.

RATIO OF MAINTENANCE EXPENSE TO VALUE OF EQUIPMENT.—In some instances, ratios of expense of maintenance labor and of material to the value of equipment in the plant may appear more satisfactory. One influence in its favor is that, in budgetary control and expense allocation, the same base can be used as for the calculation of depreciation. As a means of comparison between plants, the investment ratio is open to same objections as the plant-force ratio. Size and age of units, intensity of use, and design of equipment may justify widely differing ratios on two machines with identical functions. Yet, in practice, similar well-managed plants often show closely similar amounts in the annual percentage of investment represented by the amount spent on maintenance. Where a satisfactory ratio can be established, it can be useful in adjusting craft personnel to changes in the amount of equipment to be maintained, and in allowing for maintenance expense in estimating the operating cost of new acquisitions.

For example, the Emerson Engineers state:

Our experience over a period of years is that the annual cost of labor and material in maintenance of modern oil refineries, with well-planned maintenance programs, tends to run between 5½% and 6½% of total plant cost, excluding land. Various parts of the plants, however, show widely different ratios, as indicated by a few samples from refineries with stabilized maintenance:

Equipment or Service	Percentage of Total Original Cost
Crude storage	4.7
Steam system and lines	5.0
Electric light and power	4.0
Gas plant	5.7
Sewers and drains	12.1
Lines and connections	3.5
Fire protection	5.0
Maintenance shops	10.0
Staff houses	6.2

Labor and material components vary widely, but the plant total is about evenly divided, with materials and supplies at least as important as labor.

Along this line, one plant with 60 acres of roofs, principally felt, tar, and gravel of 20-year guarantee type, reported that the annual maintenance cost of wages, materials, and supplies is kept within 5% of the original installation cost. A crew of 5 men is kept constantly at work repairing leaks, mopping fresh tar on thin spots and replacing entire sections as needed, with replacements averaging 3 acres a year (Fact. Mgt. & Maint., vol. 99).

SELECTION OF EQUIPMENT: EFFECT OF EQUIPMENT DESIGN.—Both frequency and amount of upkeep work hinge to a large extent on the **relation of design to maintenance load imposed.** Basic ruggedness of construction, balance of moving parts, accessibility for repairs are all stressed in the theory of design, but differing ideas of machine builders on first cost and operating efficiency complicate the choice of equipment; new alloys, synthetics, closer specifications of materials and tolerances, and improved elements of construction bring about improved designs and lengthened periods of operation. The plant engineer must keep posted on developments and sources of supply, since selection of equipment is the first step in maintenance. Visiting sales engineers are valuable sources of information, but can take up excessive time; the consensus is that the plant engineer should arrange with the purchasing agent to be notified when the visiting salesman may have interesting information and decide then whether to see him.

CONTROL OF MAINTENANCE WORK.—The original status of maintenance work was that operators did their own oiling, belt fixing, and even toolmaking. Vestiges of this practice still persist. The **basic requirement of functionalized maintenance** is prompt skilled attention to machinery when requested by operators, as well as periodic attention to minimize the need for requests. Separation of the maintenance function does not mean that operators should know nothing about equipment, but that the emphasis should be on the common objective of perfect operating conditions and prompt report by operators of even suspected defective conditions. Since responsibility is placed on the maintenance department, however, all such work should be done at its direction. Operators assigned to repair work should report in such instances to the designated maintenance man.

FORM OF ORGANIZATION.—Fig. 4 shows a representative organization for maintenance work where plant investment and volume of upkeep and changes warrant a permanent plant engineer. When the plant engineer has to spend much time on alteration and installation work, the addition of a master mechanic is advisable to relieve the

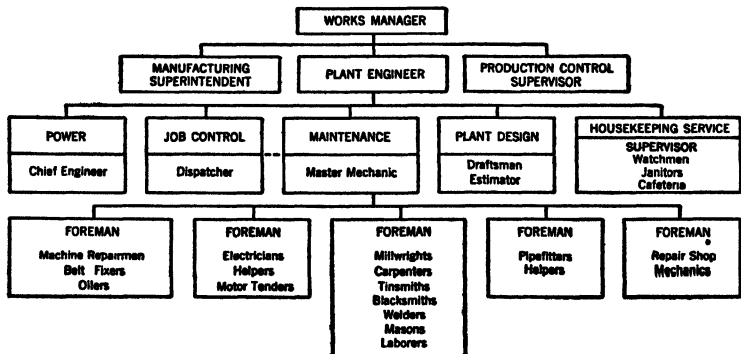



Fig. 4. Structure of a Maintenance Organization

engineer of routine supervision and instructions. Where changes are infrequent or plans are made outside, the two positions may be consolidated. In smaller plants, craft foremen may be omitted. Where the work is mostly of a routine nature, a dispatcher may be unnecessary and job control may be made the joint function of master mechanic and cost clerk. This form of organization is arranged to use any craftsman anywhere in the plant; it permits full utilization of manpower, at the discretion of the centralized planning section. **Organization of separate crews,** limited to a department, is undesirable. It leads to overmanning and, by limiting disposal of men, slows up dealing with emergencies or peak loads. However, organization by crafts for the whole plant does not prevent localized routine daily assignments. Such assignments are made when efficiency dictates, but authority remains with the master mechanic to borrow men from any postponable routine for more urgent work.

ASSIGNMENTS OF WORK TO CRAFTS.—Formulation of instruction for doing maintenance work, as described later in this Section, will permit economy of work assignments. Too rigid separation of work between crafts is to be avoided in favor of consolidating work. Splitting up a job between crafts may be avoided by giving adequate instructions. Thus, on conveyor maintenance, the largest part of the work falls within the millwright class. If the millwrights are instructed also on visual inspection of motors, they can make the frequent external inspection of motors along with the regular complete conveyor inspection. Electricians then will make the more complete inspection with instruments at longer intervals.

The common practice of **assigning a territory or group of machines to one man** to inspect and adjust simplifies maintenance supervision. An inherent danger is that the work load may change and become either more or less than a fair day's work. Such assignments, therefore, should be subject to periodic review. It is advisable to issue work tickets to each man for each day's work, as will be subsequently explained.

MAINTENANCE WORKING HOURS.—Some maintenance jobs must be performed while machines are stopped and, as far as possible, should be done outside of regular operating hours. Examples of such work are belt maintenance, conveyor and overhead crane inspection and repair, and inspection and adjustment of electronic controls. It is often feasible to arrange for a part of the maintenance crew to work staggered hours, coming in an hour earlier or an hour later than the regular force, so that they can work during the regular noon lunch period while the plant is shut down. This plan requires careful planning and scheduling of maintenance work and acceptable arrangements with the men doing this work, but establishes equality of working hours without overload and necessitates overtime for emergencies only.

Maintenance System

ASSIGNMENT OF WORK.—Good maintenance through definite assignment of jobs is dependent to a large extent on records of past work done. Definitely cleared assignments of work avoid conflicting in-

structions. The record of each job done is the basis of maintenance control. Hence, the cardinal rule is that no maintenance work should be done without a written job order or work ticket. Except in sudden emergency, the issue of a job order should precede assignment of the job to a man. In case of emergency, men may be sent to the job by verbal instruction, but a covering order should be issued promptly, with notice to persons affected by removal of maintenance men from jobs they are already on and the stopping of routine jobs.

ORIGIN OF WORK ORDERS.—Work orders may originate from:

1. Prescribed regular inspection routine and maintenance requirements uncovered by inspection.
2. Operating department request for maintenance or repair work.
3. Changes initiated by management, production or engineering departments.

To avoid conflicting claims and promises, all work should be cleared and scheduled by a single authority, who will be the plant engineer or his delegate. The general rule is that requests from departments should clear through this central point. Exception may be made where the maintenance man has a standing assignment on the upkeep of a group of machinery and the request is for minor adjustment only.

FORM OF JOB ORDER.—The simple order form shown in Fig. 5 (Ross, Maint. Eng., vol. 90) was used in a hardware manufacturing company employing about 250 people. The order is made in duplicate

MAINTENANCE WORK ORDER	CHG. ACC'T ______		
DEPT______ WILL PLEASE PERFORM THE FOLLOWING WORK			
DESCRIPTION:-	FOR MAINT. DEPT		
	Date	Man	Hours
DATE______ SIGNED______ DEPT______			

FIG. 5. Maintenance Work Order

by the foreman of the department requesting the work, the original being forwarded to the maintenance supervisor and a copy retained by the foreman. Upon being approved, the original becomes an order for performing the work. After the job is completed, the order is for-

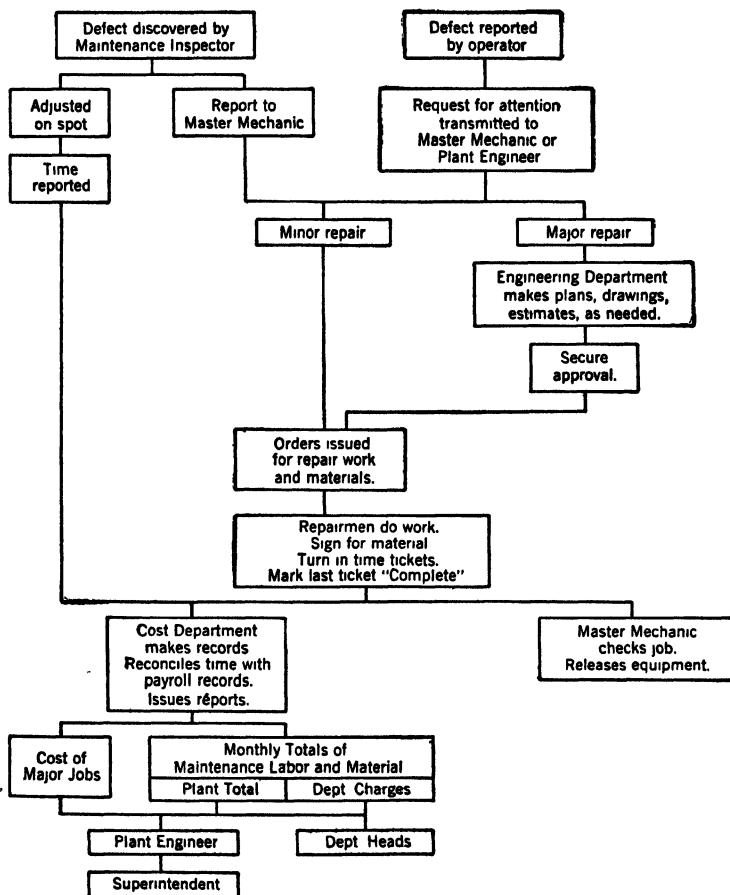



FIG. 6. Maintenance Order Routine

warded to the cost department. Time and material may be noted directly on this order, although with most companies using such a maintenance order, time tickets and material requisitions similar to those on productive jobs would probably be used.

A job order routine for major, minor, and emergency jobs is shown in Fig. 6.

Fig. 7 shows a form designed for use where work often requires several men in the crew, and is a combination work order and time ticket.

The form also shows suggested items to be checked before issuing the order:

1. Is equipment available and safe for maintenance men?
2. Is material needed on hand in the storeroom?
3. What tools are to be used?
4. Are sketches or drawings to be given out with job?
5. Is there any deadline for completion?

Forms sometimes have the order on the face and time entries on the back. This practice is not recommended. Shop copies are often folded to keep the face clean, and the back becomes soiled. Moreover, subsequent reference, checking, etc., is simpler with data all on the face. Usually two copies are made, a white carbon being kept at the order desk and a buff original going out on the job. If the organization is large, with many orders, and triplicates are needed, the form can be made to fit the billing-type register.

ACCOUNT NO	EQUIPMENT NO	LOCATION	JOB ORDER TO	REPORT O K	ISSUED AVAILABLE	JOB NO
DESCRIPTION OF JOB		CRAFT		EST HRS	WANTED BY	
		HELPERS		ACT HRS	COMPLETED	

DESCRIPTION OF JOB (cont.)	CLOCK NO	A M START	A M FINISH	P M START	P M FINISH	OVERTIME START	OVERTIME FINISH	HOURS REG	HOURS OVER	RATE	COST
MAT'L REQUIS'N NO.											
TOOLS											
SKETCH DWG NO											
AUTHORIZED BY											
TIME REPORT BY JOB COMPLETE INCOMPLETE											

FIG. 7. Combined Job Order and Time Ticket

In most cases **written instructions on job orders** will and should be quite brief. More elaborate instructions will usually be covered by a standard practice procedure or a memorandum to the master mechanic. The space provided on Fig. 7 has proved ample for all regular work. Note that equipment and location designations avoid the need for explaining further on the order where the job is. Material requisitions are made to match. They are attached to the job order and further diminish the need for explanations on the job order. Materials carried in stores should be coded for convenience of identification and withdrawal.

MATERIAL REQUISITIONS.—A material requisition form should be made out as a receipt for all withdrawals of items from stores. In most cases the exact requirements for a maintenance job can be predetermined, but provision must be made for items for which need

is disclosed only after dismantling the equipment. For this purpose the master mechanic or inspector should be provided with a requisition book.

The blanks should have spaces for entry of account number and equipment number to be charged with the material. Requisitions are often numbered serially. Two copies usually are sufficient, the original being issued to the worker with the job order and the carbon being retained for office use. Authority to issue material requisitions for repairs and renewals will ordinarily be vested in the master mechanic or inspector. On major alteration and installation work, the plant engineer will authorize the preparation of a bill of materials from which the requisitions will be written. Where heavy material is delivered directly from incoming car to job, without physically passing through stores, records nevertheless must be kept of their arrival and use. Often one simple requisition showing vendor, vendor's invoice number, and the value will suffice. Such a step insures proper entries in maintenance cost records and stores records.

Further uses of **job order and material requisition forms** will become clear as subsequent steps are described. Fig. 6 indicates graphically the representative procedure.

PLANNING MAINTENANCE WORK.—To promote economy, there must be orderly **disposition of maintenance manpower** to fit current requests and routine needs. While the plant engineer is generally responsible for plant condition and maintenance procedure, it is often advisable to relieve him and his master mechanic of duties pertaining to the daily routine of work assignments. Such duties may be delegated to an assistant, who will function as job order clerk or maintenance dispatcher. He will be responsible for all maintenance records of work done and schedules of work to be done, checking material requirements, and finding out whether these materials are on hand in stores. If any necessary materials are not carried, he must put through purchase requisitions for them. He will actually issue orders and requisitions, securing approvals as specified, and report to the plant engineer as to the relation between personnel available and work ahead.

To facilitate orderly procedure, appropriate routines are needed, as follows:

1. **Approval** of the plant engineer may be required when estimated cost of labor and material exceeds a given maximum, usually about $25. The plant engineer may set a detailed policy covering classes of expenditure he desires to follow up personally, or equipment slated for early replacement. On major alterations or acquisitions, approval of expenditures and appropriation of funds by the superintendent or other plant executive may be specified. The limit for jobs done without executive approval commonly ranges from expenditures of $250 to $500, or about 5% of monthly budget.
2. An **equipment record** is vital, to show the maintenance history of each important piece of equipment. This record will be described in later paragraphs.
3. A **schedule of work ahead** is required. This schedule will be made up of three classes of work: (1) jobs which can be definitely planned well ahead, such as inspections and routine jobs, (2) jobs which may vary with conditions but nevertheless must be fitted in at approximate times, and (3) jobs which must be done as emergencies

arise. To fit in the latter jobs, flexibility in the master schedule is necessary.

4. A **tickler file** in which work orders and data on forthcoming jobs to be done can be filed according to the date on which such jobs must be planned and scheduled.
5. A **daily work program,** made out from the schedule of work ahead, and fitting in emergency jobs for which orders or requests have just been received.
6. A **daily force report** showing the disposition of the maintenance men according to the kind and location of jobs to which they have been assigned for the particular day.
7. An **estimate of man-hours** must be made up for jobs but is a difficult undertaking. Much help can be gained by keeping a file of completed jobs for reference. On work with repetitive elements, standards, as explained later, can be gradually established.
8. A system of **long-term planning,** or annual planning, can be adopted to build up a stabilized maintenance force and a well-balanced maintenance program established, as indicated in a subsequent part of this Section.

SCHEDULING MAINTENANCE WORK.—The scheduling of maintenance work involves two steps—the **master planning** of jobs whose time of performance can be reasonably closely predicted in advance, and the **daily adjustment of this master plan** by fitting in all request or emergency jobs which have just come up and which possibly necessitate realignment of the already scheduled jobs, to meet the current situation as to immediately required work and the force and equipment available to do it.

While a **tickler file** is convenient for assembling the work orders and data for forthcoming jobs and bringing them to attention in advance of the necessary starting date, it does not schedule these jobs according to the hours of work involved as compared with the labor time available, and the specific time at which they should be undertaken. For these latter purposes either a **schedule of work board** or a **Gantt chart** (see in a later paragraph) are of greatest use.

Routine inspection—except longer jobs on heavy equipment or on building structures—perhaps may more conveniently be handled through a tickler file or **visible record system** (see later under Equipment Records) from which job orders, if necessary, could be written or the time schedule developed and put on the daily work program sheet. From this work sheet the total load on the maintenance department can be built up to the labor hours available and the men finally assigned. Maintenance jobs usually are short and usually isolated, in contrast to production jobs. Scheduling, therefore, is more immediate and must be more flexible than in production. Nevertheless, the jobs must be carefully scheduled to make the best use of the men's time and must be performed on schedule—or at once in emergency—to avoid interruptions to production or plant shutdowns. When on one occasion a flanged connection in a main steam line broke in one of the large plants operating on a 24-hour schedule and employing thousands of workers, shutting off the power and heat and closing the plant down for several hours, schedules of maintenance work were, of course, for the time being forgotten.

Mechanisms for Scheduling Work.—To control maintenance work on jobs other than short routine operations which would take too much

EQUIPMENT REPAIRS	JUNE 11 SUN.	12 MON	13 TUES.	14 WED	15 THURS.	16 FRI	17 SAT	18 SUN	19 MON	20 TUES
Pattern Shop				RE-690			RE-735			
Foundry—Coreroom	RE-715			RE-733		Moved to June 14 RE-733				
Foundry—Molding Floor	RE-707					RE-723 (2-10)				
Foundry—Sand Preparation		RE-721 (5-10)						RE-724		
Drill Press Department			RE-728				RE-732			
Milling Department		Moved to June 19 RE-705			RE-727				RE-705	
Planer Department				RE-718						
Automatics in Department A	RE-730								RE-740 (5-12)	

Light lines at the middle of the angles represent the time when work was put in on the job. The heavy lines at the bottom of the angles show the percentage completion of the jobs. Where a job is done on time, the light and heavy lines will both fill the distance between the angles. When a job is behind schedule because workers were called off it to do some other work, the gap between the angles will not be closed. In this case the light lines cover the actual hours when work was performed, but the heavy line will still lie within the angles and will show percentage of work completed.

The V at the line ending with June 14 is the current date. It is erased daily and moved ahead. Job RE-715 is done but the crew were working elsewhere for part of the day and stayed late to finish. Job RE-728 still has work to be done on it, the crew having started it late, and having quit for other work. Job RE-705 has been moved to June 19. Job RE-718 is ahead.

FIG. 8. Gantt Chart for Maintenance Work

time and be too costly to post on work boards, some kind of board such as used to schedule production is useful. Down the left-hand side of the board a list of the departments or equipment requiring maintenance work can be posted. Across the top of the board a date scale (Saturdays and Sundays included) can be entered. If the board is of the pocket, groove insert, spring clip, or similar type, work order forms, or an identification card or slip, can be put on the board opposite the department or equipment to be worked on and under the date when the job is to be done. If the work will require several days, a series of copies of the order or identification cards can be posted under the respective dates.

Obviously, the job order number, name or number of equipment and class and kind of work to be done would be shown on the job order or identification slip. As jobs are done the slips can be removed, any required data entered, and filed for posting to permanent records. A nail or peg put at the end of each date period across the top of the board provides a means for hanging an **indicator string** down over the board to be moved along daily to the close of the previous day. Any tickets to the left of the string show work behind, those to the right show work ahead. By having the department or equipment names on cards (unless there is always work at such places) the listing down the left side of the system can be kept flexible and the list may be kept shortened. The date entries also may be on strips or cards so that the board may be reposted when the last few days currently showing are approached.

An alternative plan is to use a **Gantt chart** which is essentially the above method recorded on paper. The left-hand list and top date-scale are the same as on the board. The string is replaced by a large V in pencil at the end of the previous day, and erased and moved ahead each day. Entries are made in pencil or ink, and changes are made by crossing out previous postings, noting to which date the job has been moved forward (or back) and making the proper entries at this new point. A chart of this kind is shown in Fig. 8. The right- and left-hand angles show when jobs are to start and be finished. The light line connecting them marks the time during which the maintenance work will be going on. The date scale can be adapted to whatever kind of shifts and whatever hours maintenance work is done. The work order number, machine or equipment symbol or number, and any other important indicators, can be entered on the chart.

As the work is done, a light line is charted on the date when it was performed and is extended from day to day if the job is long. A heavy cumulative line is charted below the light line as a summation of the days' work on the job. If work is stopped and then resumed, the light line will be broken and will begin again on the date when the work is restarted, but the heavy line will be kept continuous (to the same scale). Therefore, the number of days which it lags behind the current date will tell how many days the work is behind schedule.

SCHEDULES COVERING DIFFERENT CLASSES OF WORK.—The Airtemp Division of the Chrysler Corporation operates its maintenance work on a well-planned schedule basis (Siff, Fact. Mgt. & Maint., vol. 101). A 2 weeks' schedule is laid out in advance every 2

weeks at a meeting of the plant engineer and his staff, and covers work to be done and requests for repairs from all sources. Routine maintenance items are omitted from this schedule. Emergency repairs are made immediately and do not come before this committee. Factors in the scheduling are time estimates on the work, availability of maintenance equipment and materials, availability of necessary drawings, and plant production and operating schedules. Work orders assign jobs to the different maintenance departments and copies of the schedule (Fig. 9) are sent to all maintenance foremen and group leaders, and to the plant management.

MAINTENANCE SCHEDULE
ISSUED ORDERS
(This program is subject to change as may be necessary due to emergency demands)

Work Order No.	Description	Rating	Date Issued	Estimated Completion Date	Percent Complete	Remarks
	Overhead monorail conveyor, Bldg. No. 13	A 1	1-20	4- 3	30	Materials received 3-17-
	P.I.V. control	A-1	1-20	5-31	0	Awaiting favorable weather
	Intake piping spray booth, Bldg. No. 3	A-2	1-21	4- 2	60	Awaiting favorable weather
	9 sump boxes, Bldg. No. 11	A-2	1-29	4-30	90	Awaiting favorable weather
	Storage Building for inflammable materials	A-1	12- 9	3-27	90	
	Drum rack for above	A-1	12- 9	3-29	0	
	Alter rinse tank DPC-8868-CC119	A 1	3-16	3-24	95	
	Alter rinse tank DPC-8867-CC119	A-1	3-16	3-27	0	
	Alter anodizing tank	A-1	3-16	3-24	90	
	Paint interior of Bldg. No. 7	A-1	3-18		0	Awaiting vendor's material
	Move oil burner parts	A-1	3-20		0	
	Stock cupboard, Dept. 78-3	B-2	2- 3	4-17	0	
	Book case, application eng. dept	B-2	2-23	3-29	0	
	6 posture stools	B-1	2-25	3-27	0	Fabricated by Dept. 73
	Welding curtain	A-1	2-25	3-31	0	Material received 3-16-
	Communications system, eng. lab.	B-1	3-18		0	Awaiting vendor's material
	Bench, toolroom	A-2	3-20	3-31	0	
	Install No. 3A high-speed hammer, Dept. 80	A-1	2-26	3-24	0	
	Paint aluminum scrap tags, barrels, and tubs	A-1	2-19		0	Materials received 3-22-
	Replace rear door lock leading to factory	A-1	3- 8	4- 5	0	Awaiting vendor's material

FIG. 9. Two Weeks' Schedule of Maintenance Order Sent to Maintenance Foremen and Group Leaders

The current work schedule and progress reports on unfinished jobs form the basis for the next 2 weeks' schedule. New construction usually is done on the first shift, nearly all scheduled maintenance on the second and third shifts to reduce shutdowns and interference with production. In addition, an inspection schedule for routine preventive maintenance is in regular operation and no shutdown has occurred for many years. Much of this inspection is done on Sundays.

Another separate schedule is made up for general maintenance covering an entire season's work on more extensive jobs, as indicated in Fig. 10.

SCHEDULING OF INSPECTION WORK.—As has been stated and is already evident, the above comprehensive plans are not so well suited to regular inspection and adjustment or merely minor repair of building structures, building services, fire protection and safety devices, and manufacturing equipment. A tickler file system, or the visible index systems of the hinged, center panel post, vertical card, or insert types,

are far better adapted to such short-cycle, repetitive jobs. The advantages of such flexible systems are the absence of expensive posting time and "pencil work," ease of making quick changes, high degree of flexibility, rapidity of locating data, and graphic control features. Explanations or illustrations of such systems are given in subsequent paragraphs.

A form of equipment index used for the scheduling, control, and recording of inspection work in maintenance is illustrated in Fig. 11. Williamson (Maint. Eng., vol. 89) describes this system as it has been used in the Carborundum Co. It consists of visible index cards for each piece

GENERAL MAINTENANCE SCHEDULE

OPEN ORDERS 3—22—

Spring and Summer—19—

BUILDINGS:

1. Remove 10 monitors from roof, north end of Bldg. No. 3. Prevent leaking
2. General roof repairs
3. Paint exterior of all buildings
4. Repair and clean gravity tank
5. Repair window sash and replace putty where necessary

ELECTRICAL POWER AND LIGHT SERVICES:

1. Make power factor survey in order to determine advisability of increasing feeder capacity to Dept. 80
2. Paint all roof feeders
3. Wash all reflector shades and windows

STEAM PLANT:

1. Complete furnace and stoker repairs
2. Internal inspection of boilers and steam main
3. Install mechanical coal handling equipment
4. Check all return piping and trapping
5. Install raw make-up water regulating valve
6. Repair all unit heater leaks

GROUNDS:

1. Repair and grade road running around plant
2. Fill in and grade parking lot

FIG. 10. Schedule of Seasonal Work in Addition to That in the Planned Schedule

of equipment. At the top of the card the data on the equipment are entered. Below this section is an area ruled off into 52 spaces for weeks of the year, and down the left of the area are spaces to enter the years. The squares are for checking the performance of maintenance inspection as to weeks when the work was done. If the inspection card is marked O.K., a check mark is entered in the proper square. If any repairs are made, a serial number is put in the square for the week and in the next lower section of the card, beside corresponding numbers, details of this work are given. Along the lower section of the card, visible below overlapping cards above in the file, the number and name of the equipment, its location, and the inspection interval are inserted, thus indexing the card. At the bottom edge are the numbers 1 to 52. Signals moved along in the transparent holder are set at the week of

PURCHASED FROM | COST | DWG. NOS. | SPARE PARTS REF.

WEEK OF YEAR

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
'44	✓			✓			✓			✓			1			✓			✓			✓			✓			✓			2			✓			✓			✓			✓			✓			3			

WORK DONE AS RESULT OF INSPECTION

1 Replaced worm in main reducer drive
2 " bearing " " drive motor
3 " worm " " reducer drive
4
5
6
7
8
9
10
11
12
13
14
15
16 Regular inspection indicated by
17
18 green tab
19
20
21

22 – 36
37 Special inspection indicated by red tab
38 – 42

MACHINE NO. 4 NAME OF MACH. Button BLD'G. NO. 1 FLOOR NO. 5 INSPECTION PERIOD 3

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52

FIG. 11. Equipment Index of an Inspection System

the year when the next inspection is to occur, regular inspection being indicated by a green signal and special inspection by a red signal.

A brief description of the equipment, and data on spare parts, supplies, special items, and the kind of inspection necessary may also be indicated on the card. Additional records or information may be entered on the back. It is preferable to make out a separate card of this kind for each distinct kind of inspection work on each piece of equipment, such as mechanical inspection, electrical inspection, lubrication, oil change, etc. While the entries may be made on one card and distinguished by colored signals and checks or entries, such a plan is likely to be confusing.

The inspection work card given out when work is done under the above plan is shown later in Fig. 20.

Inspection charts are sometimes used for scheduling inspection as shown further on in Fig. 24. When such charts are used as schedule boards, the listing of equipment may be in permanent entries, and replaceable sections may be provided for the actual scheduling by dates. These sections may be removed when the time is past, and replaced by others with future dates. The making up of an entire new chart at any time is thus avoided. (See also, under Maintenance Methods, a discussion of scheduled maintenance of lighting equipment.)

TICKLER FILE.—A tickler file for inspection maintenance work consists, essentially, of file folders or guides (often for letter-sized forms) for successive days of the year. One method is to have folders numbered from 1 to 31 and guides labeled with months of the year. The folders for each month are put behind the respective guides and in the folders are filed the memos on job orders which should be taken up for scheduling on these dates, the work to be done at a later time according to the schedule set up. Data on the work may also be filed with the memos or job orders. For repetitive work, sometimes permanent cards are made out on which data on the work and dates for the card to come out of the file for attention are entered—thus, to come out "Monthly on the 20th," or "Weekly on Thursdays," etc. These cards are properly refiled as they come back to the file clerk.

Newer forms of tickler file folders (Remington Rand) have transloid tops in the left-hand portion of which there is room for an index insert showing what kinds of items are in the folder, next there is a list of months with a red movable signal, and to the right a list of days of the month, 1 to 31, with a green signal. The signals may be set for month and day on which the items in the folder should be taken out for attention.

For convenience, the folders may be moved to the back of the file as each month passes and the latest month thus kept in front and, when the maintenance load is light, future work may be advanced and done currently.

DAILY PLANNING AND SCHEDULING PROCEDURE.—Coordination of maintenance work is improved by planning each day for all assignments to be made on the following day. Objection is sometimes made that emergencies will make such a plan unworkable. Actually, frequent emergencies indicate either undermaintenance or poor control. Some emergencies will always occur, but they can be reduced to between 10% to 20% of the total jobs. The daily work plan shows

the location and jobs of each crew and makes it easier to get emergency help with the least possible disruption. Cooperation of department heads decreases last minute requests.

The usual practice is that **forenoons are used by supervisors to acquaint themselves with the status of all work** in progress and current operating conditions. Any maintenance requests from operating departments for work the next day should be on the dispatcher's desk by noon, any received after a deadline, which may be 2 P.M., are considered emergency orders, with a count kept of all emergency orders and their origin. Meanwhile, the dispatcher will have checked the tickler file for routine work due and the status of various crafts as to work ahead. If there is shortage or excess of immediate jobs for any craft, he will notify the master mechanic of the situation for his consideration while on the tour of inspection. Any conferences on the immediate program with the plant engineer, department heads, or chief executive may be arranged around the lunch hour. A regular **daily planning conference** should be an inviolable schedule, with 2.30 or 3 P.M. a suitable hour. Its purpose is to make complete plans for following day, which is usually done by the master mechanic and dispatcher. The dispatcher's function is to outline the job program and priorities, and release only jobs on which all items are available. The master mechanic will govern the assignments of men as best suited to the nature of the work. Assignment can be aided by using the list of craft leaders with their regular helpers, followed by lists of men used for general work, marking assigned jobs against men to prevent duplicating or missing assignments. A full day's work should be assigned to each man. Job orders may be prepared ahead, but are issued at this time, any time allowances shown being checked by the master mechanic. When the work is well organized, assignments and issue of orders for a crew of 50 men can be done in less than an hour. In very large plants the procedure may be modified, the dispatcher having separate sessions in turn with the millwright foreman, electrical foreman, and yard foreman.

Job tickets for the next day may be distributed to craft leaders before quitting time as they come in to the tool crib to turn in tools. Hence, job orders should be at the tool crib not later than 15 min. before quitting time. This method saves time and confusion of organizing crew each morning. It is also useful to notify the crib attendant about tools and materials needed, because requisitions will accompany job orders so that he may have the tools and materials ready for the jobs. Any minor adjustments needed in the morning may be readily handled by always having some postponable work in the daily schedule.

Daily Work Program.—Where work takes maintenance crews over scattered buildings and floors, the master mechanic will need a daily reference sheet. Operating foremen and the superintendent may wish notices of equipment under repair. To meet such needs, after work assignments are made, a list of jobs slated for the next day may be made up. This list may be made up on a mimeographed blank giving the names of craft leaders, the jobs on which they have been assigned, and where these jobs are located—equipment numbers, building floors, and bay numbers. Carbon copies can be made for the plant engineer, superintendent, tool crib, and dispatcher. This plan also aids in locating men when wanted.

Daily Force Report.—Job tickets will be returned after they are checked by foreman or inspector, and will show the time taken. They will require reconcilement with clock time cards, a check which is usually made by the cost clerk or payroll clerk. Originals may be used for cost and payroll records. The clerk can pick up the corresponding batch of duplicates kept by the dispatcher and mark on them the time actually used (omitting start and stop times) and labor charges, then return the batch of duplicates to the dispatcher for use in maintenance records. A **summarized daily maintenance payroll** may be prepared by the cost clerk and sent to the plant engineer for signature and forwarding to the works manager. This payroll sheet serves as a constant check on the number of maintenance personnel. Job order numbers will identify the work being done on jobs for which appropriations have been made, so that any such expenditures can be shown separately to account for any temporary increase over normal.

REPORTS ON CONSTRUCTION.—The customary practice on new construction is to engage outside contractors, but the plant engineer may be responsible for seeing that the plans are carried out, and may exercise the function of the architect's supervision and check progress against schedule. Plant alterations may have to be carried out in stages to minimize interruptions to production. Such work is difficult to contract, and if the plant has the nucleus of a construction crew, it may be preferable to have the plant engineer handle the whole job. Where the engineer is responsible for construction cost, the representative practice is for him to report periodically on the percentage of the job physically completed and the actual labor cost to date against estimate, with a report on material cost to date indicating any substantial materials charged but not used. If the work is planned and scheduled and materials are allotted, a check of progress against due dates may provide all the control needed.

FILING COMPLETED JOB ORDERS.—Records of work done are often required for future reference and play an important part in control. Many jobs will be completed on one ticket. Where several tickets are issued, a simple suspense file may hold the tickets until the last one comes in, showing that the job has been checked off as complete. The tickets may then be stapled together. Before filing them, entries should be made on the equipment record (described in succeeding paragraphs) showing the date, total labor cost, total material cost, and other important notations. A suggested method of filing job and material tickets is by equipment number because a search for information will most frequently relate to a particular piece of equipment. Where information on craft activity is wanted, the best source will be file of the daily work programs.

Equipment Records

KINDS OF RECORDS.—There are two main kinds of equipment records. One is kept for the purpose of recording data on the equipment itself—name, number, or symbol, date of purchase, cost installed, maker and model, location in plant, changes or additions, current condition,

perhaps a calculation or estimate of current value, and record of final disposal. Such a record forms the basis of efficient maintenance work and should be kept in the plant engineer's office, where current entries can be made when the equipment is altered, repaired, moved, or disposed of. The record forms a **history of the machine** and a basis for certain production planning.

Another use of such a record is for **accounting purposes.** In making financial reports and in preparing tax returns, the amount and value of equipment in the plant must be ascertained or estimated closely and an equipment record system is therefore practically imperative. Since depreciation enters into the calculation of equipment value and the determination of tax payments, an equipment record provides for the correct and systematic entry of data which alter the value of machines, such as additions to or removal from the machines of attachments, etc., and deterioration due to normal use, contingencies, or gradual obsolescence. The accounting department may therefore wish to have the same, or a similar, record at the plant engineer's office. In other cases a single record may be kept in the one department or the other, for the use of both departments. However, it is better to keep it in the plant engineer's office, especially when detailed entries of maintenance work are made, as they should be. In this case the accounting department needs should be provided for on the records, and care should be exercised to see that data for this purpose are kept posted.

A second kind of equipment record is that used for the purpose of **entering all details of maintenance and repair work** on equipment. In this same connection a signaling system can be provided on the records to handle regular or periodic inspection and adjustment work for preventive maintenance on equipment. This record calls for data of a kind different from the equipment history card discussed above, which is suitable only for general maintenance control and for accounting purposes. Either or both of the records may be kept on cards or in a loose-leaf record book.

In Fig. 12 is shown a machinery-equipment Kardex foldover record card used by Vultee Aircraft, Inc. Complete details of the machine are given, including its final disposal. Since this card system was established during the second World War when the government financed the purchase of considerable equipment, the Defense Plant Corporation inventory number was used as the basis for indexing, the insert showing also the name, make, and model of the machine. This foldover 8 x 5-in. form provides columns on the back for a cost summary of the installation: machine, freight, installation, foundation, other costs, and total cost.

In the Fairchild Aircraft plant, a Kardex record of the same general nature as the one in Fig. 12 is used, but with different entries arrangement and a few more details. A feature of this latter record is the listing—along the two visible edges of the foldover form—of numbers from 1 to 50 on one edge, and 51 to 99 on the other edge. Plain and punched hole signals over this double scale show the department where the equipment is currently located, the plant number being printed on the signal itself. Thus, a machine may be in Plant 10 (number of signal) and in Department 33 of that plant. A current equipment inventory by plants or departments can thus be quickly taken.

FIG. 12. Machinery-Equipment Record Card

Equipm't No.	Name	Size	Capacity				Maintenance Expenditures		
							Period	Labor	Material
Maker's No.	Maker					Eng. File No.			
P O. No.	Bought From	Purch. Price	Freight	Erection		Cost Installed			
			Wt Lbs	Height		Floor Space			
			Aver. H.P. Max.			Speed			
			Belt	Pulley					
			Type	Motor No.					
			Speed	Pulley					
			Rating						
Date New Installed		Location in Plant							

FIG. 13. Plant Engineer's Equipment Record

INVENTORY-TYPE OR HISTORICAL RECORD.—The inventory-type or historical record, useful in part for certain accounting data, is the simplest form to keep.

COMBINED EQUIPMENT DATA AND MAINTENANCE COST RECORDS.—Fig. 13 indicates a type of card on which general information may be entered for quick reference. The design of a card for universal use throughout a plant is difficult and such a card should have a blank space for special entries. Unusual cases may be handled on the 5 x 8-in. card shown in Fig. 13 by entering information on a blank 4 x 6-in. card and stapling it to the regular card, of which only the top and right-hand side will then be used.

A suggested method of **supervising maintenance cost** is to use two files. The plant engineer or master mechanic will have the equipment

0 | No.'s end'g 1 | No.'s end'g 2 | etc.

Maintenance Record on.

Order No.	Items	Labor	Mat'l	Order No.	Items	Labor	Mat'l

FIG. 14. Equipment Record of Maintenance Expenditures

BRASS TAG EQUIPMENT

WESTINGHOUSE ELEC. & MFG. CO
RADIO DIVISION — BALTIMORE WORKS

VENDOR | PUR REQ NO. | DATE INSTALLED
MFG | DATE PURCH'D | DATE TAGGED
DESCRIPTION | DATE REC'D | WGT

COST | LOCATION
NET PRICE | DATE | DEPT | BLDG. | AISLE | COST CENTER
ACCESSORIES
SERIAL NO | B T. NO | TRANSPORTATION
H.P. | R.P.M. | AMP | MOTOR
PHASE | VOLT | FRAME | ELEC. EQUIP.
CYCLE | BEARING | MODEL | INSTALLATION
☐ AIR ☐ WATER ☐ DRAIN ☐ GAS ☐ VENT ☐ COOLANT | TOTAL

ACCESSORIES | DATE | PUR. REQ No. | COST | REMARKS

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 … 22 23 24 25 26 27 28 29 30 31 32 33 34 35 … JUL | AUG | SEP | OCT | NOV | DEC

B.T. 2177 MCH. Turret Lathe W & S #5

FIG. 15. Record Providing Detailed Machine Data and a History of Repairs

CAR NUMBER A-557 MAKE Chrysler YEAR 19

MOTOR VEHICLE MAINTENANCE SUMMARY

CAT NO. 1-8926

NO.	MILEAGE OPERATED	GAS	OIL GREASE	TIRES	MISCELLANEOUS REF	MISCELLANEOUS AMOUNT	REPAIR PARTS	REPAIR LABOR	OUTSIDE REPAIRS	MONTHLY DEPRECIATION	TOTAL	CENTS PER MILE
J												
F												
M												
A												
M												

CAR NO. MAKE YEAR PAGE NO.

MOTOR VEHICLE MAINTENANCE WORK SHEET

CAT NO.

DATE	GAS	OIL GREASE	TIRES	MISCELLANEOUS DESCRIPTION	MISCELLANEOUS AMOUNT	REPAIRS DESCRIPTION	REPAIRS PARTS	REPAIRS LABOR	OUTSIDE REPAIRS DESCRIPTION	OUTSIDE REPAIRS AMOUNT	TOTAL

Fig. 16. Motor Vehicle Maintenance Master Record. Work Sheet and Summary

card file. The maintenance dispatcher will have a job order file, in which each piece of equipment or plant unit has a tab card, as shown in Fig. 14. As jobs are completed, entries are made on this card and job tickets are filed behind it. Expenditures may be totaled annually, quarterly, or periodically and the total transferred to the equipment card file, at which time the plant engineer may review the record.

An equipment record system that provides for detailed data on each machine and a history of its repairs and disposition is kept by the Westinghouse Electric & Manufacturing Co., Radio Division, Baltimore Works. As shown in Fig. 15, this Kardex system consists of a folded 8 x 5-in. form for each piece of equipment. The lower part of the form in the pocket, which is indexed by machine number—with the kind, make, and model number or size also recorded on the visible insert—contains complete information on the machine: vendor, description, purchase and installation data, complete cost location, accessories with their date of purchase and cost.

The upper foldover portion of the form shows the disposition of the machine throughout its life and data on its scrapping when it is finally displaced. A record of all repairs and maintenance, beyond ordinary adjustments, is included, with date, purchase or job order number, cost, and description. The signal system along the lower edge of the pocket enables the month and day of the next inspection to be shown so that regular upkeep may maintain the machine at its highest stage of efficiency for production.

MOTOR TRUCK MAINTENANCE RECORDS.—A record of maintenance of motor trucks, kept by many fleet owners, is typified by the Kardex system illustrated in Fig. 16. Three forms comprise the record, which conforms to the regulations laid down by the Office of Defense Transportation during the second World War. These records are the master, the summary, and the work sheet.

The master record provides space for entering information describing the vehicle. Over it rides the work sheet on which expenses to the vehicle are posted as they occur. At the end of each month the columns on the work sheet are totaled and recapped to the summary record in the upper pocket.

On the visible margin a Graph-A-Matic signal indicates the cost per mile of operation. By watching this signal in comparison to those on other records for the same class of vehicle a decision can be made as to whether vehicle should be sold or overhauled. If an overhaul is decided upon, the date is entered in pencil in the space at the extreme right. At the left a ¼-in. signal indicates the month when tire inspections, etc., are due.

RECORDS OF MISCELLANEOUS EQUIPMENT.—The setting up of an equipment record system calls for good judgment. Individual records on small inexpensive units of equipment are seldom necessary. They may be handled by means of a general departmental equipment record and account.

Records for special services, such as maintenance of belting, are kept on special forms and often require the use of special job order forms on which data may be entered by the dispatcher or the maintenance

man at the time the work is performed. The procedure is outlined later in this Section in the paragraphs dealing with maintenance of driving belts.

Job Standards and Wage Incentives

JOB ANALYSIS AND STANDARDS.—In planning work for the maintenance men, it is essential to know what is a fair assignment. In shops with unplanned maintenance, especially where repair men have a wide range of work, job assignments without adequate instruction or supervision invariably lead to excessive cost of work. Time studies of jobs hitherto unsupervised frequently yield a development of new work methods or improved tools which alone produce decided improvement. When in addition a **standard time is set up for performance,** still greater savings can be attained. Chamberlain cites some examples (Mill & Factory, vol. 19):

In one plant where time studies were taken on the periodic cleaning and turbining of a steam boiler, the job was reduced from an average of 80 man-hr. to 50. Furthermore, the boiler was ready to go back on the line in slightly more than half the time required previously.

The standardization of methods and operations in the replacement of tubes in a refinery still resulted in getting the job done in an average of 9 man-hr. where 17 had been required before. The elapsed time was reduced from 3½ hr. to 2 hr. This meant an important saving because operating time on the still was worth $50 an hour in terms of gross profit.

In every plant there are many repair jobs of a repeat nature. It is these jobs that should first be standardized. Job analyses should be prepared, based on the best-known method for making each type of repair. As the work of standardization is gradually extended, it will be found that job elements will be identical for many different types of repairs.

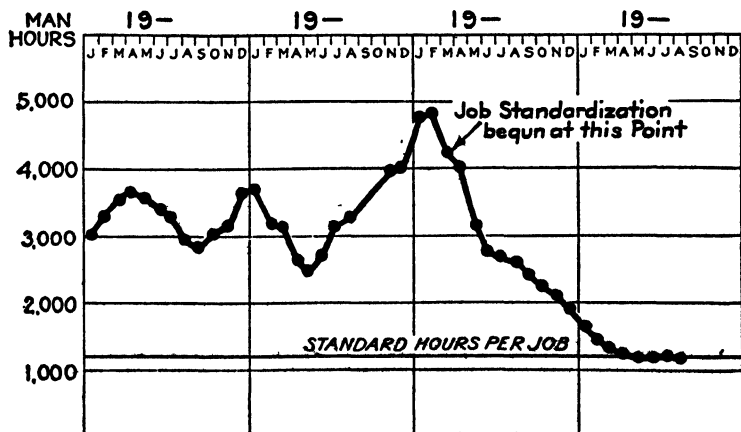



FIG. 17. Effect of Time Study and Job Analysis on Maintenance Work

Fig. 17 illustrates the effect of time study and job analysis on a large maintenance job. This is a job which has to be performed at regular intervals on each unit of a battery of similar pieces of equipment in a continuous process plant. Originally approximately 100 men were involved. By standardizing and coordinating all the elements of the job, this number was reduced to 42. The reduction in labor cost is evident from the chart—approximately 2,000 man-hr. per job or a saving of $1,400, not including a sizable saving in materials.

In spite of the reduced force the work was completed in a shorter over-all time. It is also interesting to note the gradual steady improvement with the introduction of standardized procedure.

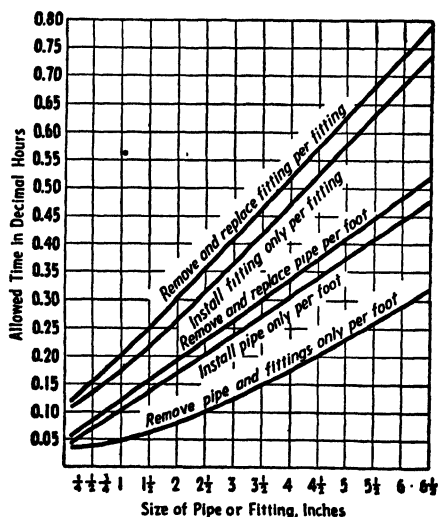
Pipefitting is an example of how standardization of job elements can be used to establish allowances for wide range of jobs. The Westinghouse Electric & Manufacturing Co. describes standards for pipefitting under various conditions (Fact. Mgt. & Maint., vol. 99). Fig. 18 gives the time allowances on operations performed when installing or repairing pipe lines in a ditch or at floor level. (See, under Maintenance Methods, a discussion of scheduled maintenance of lighting equipment, which covers setting of time standards.)

Time allowance when installing or repairing pipe lines in a ditch or at floor level.

FIG. 18. Time Allowances on Pipefitting Operations

ESTABLISHING PROPER WORK METHODS.—Standard procedure does not always involve setting of time standards. Establishing proper work methods, instructions as to items to observe, and fixing of responsibility may be covered by standard practice instructions, of which Fig. 19 is an example. In this case faulty practice in cleaning tubes of a furnace had been causing loss of time and damage. A pro-

gram of correction was devised by the engineer, the men concerned were called into conference to discuss and amend it, and assignment of responsibility was incorporated in the instructions on procedure. The job then was executed in a workmanlike and expeditious manner. As another example of this kind, the experience is cited of a company with several thousand motors operated by magnetic controls. To avoid trou-

Standard Procedure

TURBINING STILL TUBES

June 3, ...

Turbining of still tubes will be done under supervision of still fireman. Supervision includes the following:

1. Men assigned to operate turbines are to be shown how to produce a good job:
   a. Make the tubes clean.
   b. Avoid damage to either tubes or header faces.
   c. Clamps are to be set correctly and firmly on hose.

   A. In order to avoid loss of time, the turbines may be fed in without being sure that every spot is clean. Such spots with imperfect cleaning are to be picked up on the return draw.

   B. To avoid making "rings" in the tube, keep the turbine moving forward and backward all the time—never allow turbine to run on one spot. To avoid damage to header, make sure clamp is at correct distance; recheck if knocker is attached to turbine.
2. Turbining should be done as quickly as possible, consistent with good work and safe practice. See that the men use cotton earplugs.
3. Check air pressure on gage at still and report at once if pressure drops below 90 lb. Operate drain valves on air lines to keep water out of turbines. See that turbines are lubricated.
4. Fireman is to turbine sufficient tubes himself to keep posted on condition and also relieve regular operators in rotation.
5. Supervision also includes checking of time reports; each operator is to turn in time ticket showing hours worked and number of tubes cleaned.

FIG. 19. Illustration of Standard Practice Instructions

ble with poor connections, rigid instructions were issued on soldered joints:

> Wires must be cleaned bright, joint soldered hot and joint cooled with damp rag to set solder before moving it in any way that might cause loose or high resistance.

Instructions of this type, although general in application, enumerate specifically how the work is to be performed and the points needing special attention. Hence the instructions are readily enforced and contribute much to reduce maintenance trouble and cost.

MAINTENANCE WAGE INCENTIVES.—Where production workers are paid on some form of incentive basis, the same reasoning which dictated this step and also the desirability of equal treatment of all workers leads to the consideration of incentives for maintenance

workers. The objection is often made that maintenance work is not sufficiently standardized, but experience shows that, over an annual period, the largest part of such work is repetitive and therefore lends itself to method study and time study. The standards may not be so precise as in continuous production, but can be set up with a workable degree of accuracy. As to special jobs, in any case they should be studied in advance and methods and times should be outlined in connection with the planning of the work. Such estimates can be used as temporary standards.

BASES FOR INCENTIVES.—Various bases for maintenance incentives have been used:

1. Ratio of maintenance hours or payroll to direct labor hours or total factory payroll.
2. Attained reduction of the time which otherwise would be lost through equipment failure.
3. Relation between maintenance and unit production cost or department efficiency.
4. Ratio of maintenance cost to sales volume.
5. Ratio of actual maintenance hours to standard time allowed for the jobs assigned.
6. Straight piecework.

The **ratio of maintenance to direct labor** or total payroll is favored for budgeting purposes in plants with fairly steady year-round operation and infrequent major overhauls or rearrangements. It often aims at a parity of relations between operating and maintenance workers, putting both on equal hours per week. It sacrifices the opportunity for employment stabilization by using operators for maintenance in shutdown periods, hence is suited to plants with women workers or those mechanically unskilled. The basis commonly used is the ratio shown by the experience of the last few years, with 25% to 50% of savings in maintenance per pay period distributed as a bonus. The method has achieved lowered maintenance cost, closer attention to the work, and improved upkeep.

The **prevention of lost time** method is to pay the going wage rates to maintenance men and add a bonus, usually 25%, for each period with no machine delays due to defective maintenance. Where such delays occur, an hourly penalty rate is charged to the bonus account. This plan stimulates preventive maintenance, but its applicability is limited. The working out of relations between standard maintenance crews, work assigned, and the setting of penalty rates may involve more difficulty and expense than a simplified set of working standards.

Bonus based on **unit production cost** is sometimes used where machines are the controlling factor in output. This method is a modification of the prevention of lost time method, and has similar limitations.

Ratio to dollar output as a maintenance incentive develops out of budgeting plant expenses according to sales volume. It is not recommended for general use.

Ratio of actual to standard time is the most flexible plan, since work can be assigned as needed and changes in crews, machines, or methods do not alter the basis on which the bonus is set. In principle it requires that a standard time be set for each job and and reports made of actual

time taken. In practice some simplification is feasible, and much work of routine nature can be handled on a group average basis. As examples: belt-fixing may have standards stating the number of belts of each given size to be inspected and adjusted per 8 hr., with one work ticket issued for that amount; inspection, cleaning, and oiling of motors may be similarly handled; or a tour of duty may be set for tending and keeping in adjustment a block of machinery.

Installation and alteration work can be rated with the help of elementary craft standards developed for the plant, data in construction handbooks, and the use of information in the files on similar equipment, as carried on records such as Figs. 9, 10, 11, and 12. On recurring work, a study of methods to develop the best procedure will yield a time standard for the approved procedure. Use of such standards avoids underestimating, permits safer planning of the time needed, and is valuable in checking bids when an outside contractor is used. As examples, classified man-hour standards under specified conditions can be established for items such as trench excavation by cubic feet, pipe-fitter gang by diameter of pipe and hours per length and per fitting; electrical conduit per 100 ft. and by type of connections. In all such work allowances are added for starting the job, inspections, withdrawing tools and materials from tool cribs and storerooms, and traveling to and from the job. Loose setting of standards is not recommended but the nature of the work justifies a **higher margin for personal allowances** than in repetitive production work. Where 10% to 15% is commonly used in the latter, 25% is reasonable in maintenance work. For example, a job rated as 12 hr. actual work for an average man will be allowed 15 hr. against payroll time. A favored bonus basis has been one-half of the savings over standard time. For example, 10 men with payroll time of 440 hr. and base pay of $352, having completed work rated at 550 hr., have bettered the allowance by 110 hr. and will draw a bonus of 55 hr. or 12½% on base pay. An alternative method is to figure the efficiency rating and pay a bonus accordingly on an appropriate scale. Use of the group method is favored to avoid complications in shifting men between gangs.

Straight piecework is applied to maintenance work in the same manner as in production work but obviously must be used under similar conditions, namely, repetitive work upon which methods studies—and usually time or motion studies—have been carried on to set standards. Another basis is to set the standards on the history of previous identical jobs as carried on the equipment records or records of maintenance work (Figs. 11 to 16). In the absence of such studies or records, the standards can be only careful guesses. Jobs of this kind occur most often in large plants where there is a considerable volume of the same kinds of work—such as motor rewinding on standard sizes of motors—which can be done to a large extent in the maintenance shops rather than throughout the plant at the points where equipment is used.

The ratio of actual time to standard time is the most generally satisfactory basis. The straight piece rate method is best adapted for recurring jobs which have been reduced to a regular standard basis. The other methods listed have been successfully applied but are subject to certain limitations. For example, maintenance expenditures tend to be the heaviest in time of low plant activity, when the opportunity for

making repairs is greatest; weekly or monthly expenditures are not immediately related to machine performance; changes of operating equipment, methods, or products may invalidate the original basis.

INTRODUCING WAGE INCENTIVES.—When starting an incentive wage system, extreme care should be used to have a complete understanding with the maintenance force as to future modifications. The incentive idea should be promoted as recognition by the management of the importance of good maintenance and as encouragement of cooperation, attentiveness, and careful workmanship, and not to stimulate speed. The prevailing method is to handle the incentive on a group basis, either departmentally or for the entire maintenance force, with foremen participating, and to calculate and pay the incentive for regular pay periods.

The character of maintenance work is such that it is particularly important first to achieve **reasonable standardization of methods and procedures** before attempting to introduce incentives. Stable and orderly management is a prime requisite.

TYPICAL INCENTIVE PLANS.—One company which installed an incentive plan describes its operation thus:

Twenty per cent of our total force is used to maintain plants, mines, and facilities. We attempt to observe three fundamentals: (1) Use production equipment of most suitable material and design. (2) Take care of this equipment. (3) When repairs must be made, make them efficiently. Republic has taken the position that there can be standards on repair work. Time values based on time studies have been worked into formulas and tables for such operations as laying a pipe line, welding a piece of machinery, painting a building, relining a blast furnace. Men are informed of the allowed time for each operation and paid in proportion to the time saved over allowance. On jobs that have repeated themselves since the advent of incentives, the time has been reduced 40%; repair cost per unit of mill production shows a substantial reduction. We stress the fact that it is costly to slight repairs, and check constantly. We feel that our equipment is in good shape.

Regarding Use of Incentives.—Steele (Fact. Mgt. & Maint., vol. 97) describes a plan of **incentive to maintenance foreman,** based on the ratio of actual to standard maintenance cost per 1,000 hr. direct labor, a monthly bonus being paid on the sliding or moving average of the last 3 months.

While some failures of incentive systems in maintenance work are reported, the feasibility of incentive plans is attested by a compilation made by Stegemerten (Fact. Mgt. & Maint., vol. 98) listing the **proportion of maintenance work done on the basis of standard time** allowances and incentive:

Class of Maintenance Work	Percentage on Standard Time
Laborers, roofers	60
Wiremen	75
Janitors	80
Millwrights	85
Bricklayer, carpenters, painters, pipefitters, and structural steel workers	90
Pipe-covering, sheet-metal, and concrete workers, and window-cleaners and wall-washers	95

Preventive Maintenance

INSPECTION FOR MAINTENANCE.—Successful preventive maintenance depends in large degree upon an adequate inspection program. The ideal of preventive maintenance is to remedy minor defects before they cause the need for major repairs and to make renewals before the failure of equipment. Maintenance inspection is the means of translating the ideal into practice. A good inspection program will cover the whole field of plant and equipment, detect defects, and report when renewals and replacements must be made.

In large plants there may be a **maintenance inspection foreman,** reporting directly to the plant engineer. In smaller plants the plant engineer may lay out inspection schedules and assign inspection jobs to the various crafts.

The **relation of inspection to corrective measures** and the importance of records in such work are shown by Lehman (Fact. Mgt. & Maint., vol. 99) according to methods in use at the Detroit plant of the United States Rubber Co., from which the following explanatory sentences have been assembled:

With 52 synchronous motors, ranging from 250 to 2,200 hp., maintenance to insure continuous operation becomes of supreme importance. Motor failure might make it necessary to cut stock in mill rolls by hand, or steam material in a banbury mixer 6 to 7 hr. to get it out. The following tests are made a **matter of record** each month: (1) insulation resistance test on stator; (2) same on field; (3) same on control circuit; (4) air gap test with feeler gage. The monthly feeler gage test discloses, for example, if bearing wear has dropped the rotor, in which case the bearing is replaced. Insulation test readings disclose the need for blowing out, which is done with air at 80 lb. per sq. in. If the trouble is thus cleared up, the insulation is sprayed with suitable varnish. The insulation test and analysis takes about 2 hr.; and 14 to 16 hr. is allowed for the varnish to dry, or longer if the production schedule permits.

Items to be considered in organizing inspection are:

1. Detailed instruction as to construction elements which are to be inspected, measurements required, and tolerance or service limits.
2. Timing of inspections, as to frequency and coordination with maintenance operations.
3. Assignment of inspection work to appropriate men.
4. Provision for inspection records and a follow-up system.

INSTRUCTIONS FOR INSPECTION.—Both general and specific kinds of instructions may be used. The general program will fix plant policy on the various kinds of inspections to be made; what defects to look for in bearings, gears, motors, control panels, and other elements of construction; when and how to report renewal requirements; other inspection rules developed from plant experience.

Where there is a wide range of equipment, the above procedures may be formulated into **a book of inspection rules,** with alternate kinds of inspection of similar equipment, each under a separate rule number. Reference to rule number will simplify the issue of specific directions as to work required on a given inspection job.

Williamson (Maint. Eng., vol. 89) outlines a system of records and inspections used by the Carborundum Co., of which the following deals with instructions:

When an inspection is necessary, an inspection work card is filled out (Fig. 20). On this card are shown spaces for equipment location, and an index of all general kinds of inspection, one or a number of which can be checked to indicate the kind of work to be done, thereby eliminating written instructions by the clerk.

In making inspections it often proves advisable to have listed on the form given to the inspector points to be noted in making the inspection, so that a complete and thorough job can be accomplished. The inspec-

Inspection card Mach. No. 4 Bldg. No. 1 Floor No. 5

Gen. Mechanical ✓
Gen. Electrical
Transmission
Gen Lubrication
Oil Change
Spec. Lubrication
All Piping
Heating Equip
Building
Roof
Hoists
Racks
Special
Time reqd to inspect Signed

Plain bearings 70
Ball bearings 20
Rolls 6
Drums 2
Gears & Sprockets 20
Belts 40
Chains 10
Pulleys 50
Motors 3
Speed reducers 3
Controls 2
Adjusters 3
Electrical wiring & etc.
Frames

Fig. 20. Inspection Work Card Issued to Inspectors

tor will then check each item on the form as he does his work, indicating opposite any items needing attention just what repairs were required (Fig. 21).

TIMING INSPECTIONS.—The objective of timing is to space inspections as far apart as possible to reduce cost, but stay within safe limits of time during which defects ordinarily do not develop to the point of needing attention. Many inspections can be dovetailed into maintenance work, as when equipment is opened for cleaning or taken apart for adjustment and repair. Periods of accessibility and convenience are often a factor. Thus, general heating equipment may have a thorough check in early spring to list all work to be done in summer while it will be out of use.

Some companies **distinguish between visual or external inspection and testing or checking.** Thus, a main steam line might be visually

Conveyor Inspection Report No. 31

Conveyor No. *23* Section *F-12* Date *2-10-* Inspected By *G.Riling*

Motor *O.K.*

Motor drive chain is loose

Controller *Contacts burnt*

Push Button Control *O.K.*

Signal Bell ——

Worm ——

Worm Gear ——

Bearings *One bolt loose in drive shaft bearing*

Shafts and Collars *O.K.*

Gears *O.K.*

Sprocket Wheels *Set screw loose*

Sprocket Chains *O.K.*

Rollers *Bracket bent*

Load Carriers *O.K.*

Chain Guides *O.K.*

Conveyor Frame *Loose bolt in second hanger*

Guards *O.K.*

General *Clean*

FIG. 21. Inspection Report Sheet for Conveyor Maintenance

inspected weekly for absence of leaks and outward tightness of insulation, and annually checked with instruments to determine insulation efficiency. Motors may be inspected monthly for cleanliness, commutator condition, and normal heat rise, but more thoroughly checked with ammeter and megameter every 3 to 6 months, depending on severity of service.

Initial frequency of inspection will be determined by judgment and general experience with the kind of equipment in use. Inspection and maintenance records will show when the frequency should be changed.

Periods for Inspection of Buildings and Equipment.—In general, Williamson advises the timetable given in the following list:

Buildings or groups of buildings should be listed separately in the file, and inspection periods set for intervals of from 6 months to a year, depending upon climate, age, foundations, and equipment housed. Inspection of building proper should cover in detail foundations, walls, columns, girders, building joints, etc.

Roofs should be listed separately in file, and inspection periods should be set from 6 months to 1 year, depending on climate, age, and construction.

Floors should be carried in separate groupings in file by buildings or groups of buildings and inspected, depending upon their use, in periods ranging from 3 months to 2 years.

Paint should be checked at stated intervals, 6 months or more, taking into consideration protection, light reflecting capacity, and cleanliness.

Electrical power transmission equipment should be inspected in periods of 3 months or less to insure dependability.

Power-control equipment should be listed separately or in groups or territories and inspected according to use, periods ranging from 4 to 12 weeks.

Heating equipment and low-pressure steam lines should be covered by thorough inspections every month.

High-pressure steam equipment should receive attention in semi-monthly or weekly periods.

Protection equipment, such as sprinkler lines, fire apparatus, and accessory equipment, should be checked over thoroughly in intervals of from 3 to 6 months. Some portions, however, require inspection more frequently. as daily or weekly.

Fixtures, such as elevators, require not less than weekly inspections, covering both mechanical and electrical equipment.

Materials handling equipment, such as hoists (air and electric), must be covered by weekly inspections. Process materials handling equipment should be inspected in semi-monthly periods, depending upon usage.

Transmission equipment, such as line shafting, should be covered by monthly inspections, with alignment checked at least every 3 months. Other heavily loaded transmission equipment should be inspected weekly.

Equipment such as machine frames, rolls, foundations, and bases should be thoroughly inspected for flaws and checked for alignment in periods ranging from 2 to 6 months.

Oil-well bearing or any oil-reservoir equipment should have oil removed, equipment flushed with kerosene, and clean oil put in in periods ranging from 3 months to a year, depending upon service. Practice of replenishing oil supply as it becomes low is unsound.

Drinking water systems should be inspected every day; likewise **toilets** and **washbowls,** latter sometimes twice a day.

The schedule of routine inspection used in the Westinghouse Electric & Manufacturing Co. plant is shown in Fig. 22.

Inspection frequency is given by Stackhouse (Fact. Mgt. & Maint., vol. 98) as carried on in the General Foods Corp. and is condensed in Fig. 23.

Panel controls should be inspected and cleaned every 3 weeks, according to one manufacturer with over 5,000 motors on magnetic controls. Inspection also includes seeing that boxes are tight and any open knock-

Continuously

1. All Construction
2. Completed Jobs
3. Yards
4. Drinking Fountains
5. Piping
   a. Air
   b. Water
   c. Hydraulic
   d. Gas
   e. Oil
   f. Steam
6. Electric Wiring
7. Ladders
8. Electric Signs
9. Roofs
10. Fire Doors
11. General Safety

Weekly

1. Pressure Tanks
2. Shop (Regulations Committee)
3. Ventilating, ZX-1
4. Exhausters, E & I
5. Blowers, H-1

Monthly

1. Cranes
2. Jibs
3. Elevators
4. Dumbwaiters
5. Conveyors
6. Special Lifting Devices
7. Chain Blocks
8. Hoists
   a. Electric
   b. Air
9. Crane Runways
10. Trolley Wires
11. Slings
    a. Chain
    b. Wire Rope
    c. Manila Rope
12. Switchboards
    a. #1 Pwr. Hse.
    b. #2 Pwr. Hse.
    c. MF Substa.
13. Tunnels
14. Melting Pots
15. Ovens
16. Furnaces

Quarterly

1. Test Floors
2. Cable Tunnels
3. Sewers
4. Gasoline Tanks
5. Benzol Tanks
6. Floor Loadings

Monthly *(Cont'd)*

17. Enameling Towers
18. Kitchen Equip.
19. Elec. Welders
20. Portable Elec. Grinders
21. Lead Covered Power Cables
22. Power Transformers
23. Maintenance Dept.
    a. Mach. Tools
    b. Storerooms
    c. General

Semi-Annually

1. Outdoor Substation
2. Pole Lines
3. Outdoor Power Lines
4. Buildings
5. Fences
6. Bridges
7. Walks
8. Driveways
9. Fire Escapes
10. Stacks
11. Manholes
12. Safety Belts

Note: This does not include Fire Fighting Apparatus and Systems (being covered by another Department)

Fig. 22. Schedule of Routine Maintenance Inspection in the Westinghouse Plant

Inspection Intervals and Assignments

Millwrights		Pipefitters		Electricians	
Fanshafts	6 mo.	General sanitary plumbing	1 mo.	General ball-bearing motors	6 mo.
Vari-drives (belts)	6 "	Roof sumps	1 "	Welders	6 "
Drip pans conveyors	4 "	Strainers, vacuum pumps	1 "	Paging system	6 "
Differential roller silent chains	2 "	Humidifiers	Daily	Motor-operated valves	6 "
		Radiators (winter)	"	Ventilator fans	3 "
		Flowmeters	"		
		Air lines and drip traps	"		

Fig. 23. Routine Inspection Program of a Food Manufacturer

out holes are plugged. Panels are placed at maximum convenient height to minimize fouling by oil haze.

Electronic controls require daily attention. Love and Dieter (Fact. Mgt. & Maint., vol. 99) describe applications and care in the Bristol-Myers Co. Phototubes last about 2 years in daily 8-hr. service; thyra-

tron tubes about 1 year. Mechanics responsible for their inspection come in a half-hour before the operators and inspect, test, and operate the machinery. Tube lenses and other parts are wiped and dusted; the glow character of thyratron tubes is noted; all light sources are checked; operation of phototubes is checked by throwing light beam on or off; breaker points on panels are inspected daily and any oil or dust is removed. Breaker-points on direct current panels are checked for dressing every 2 months. Proper voltage is maintained across all phototubes.

Long-Term Planning

DEVELOPMENT OF THE PROGRAM.—The principal function of long-term planning is to provide a basis for a stabilized maintenance force and so arrange major jobs that peak loads do not develop into emergencies.

Where standards or good experience data are available, the most desirable procedure is to assemble a schedule of equipment and buildings and compile a **man-hour summary of normal maintenance work** required by each craft, separating craftsman hours and helper hours in each. In addition, experience and plant policy should permit an estimate of installation work, alteration, and removal work. Total estimated man-hours divided by expected normal annual work-hours per man will give the minimum average force. This number of workers is then translated into a minimum skeleton crew which, because of practical minimums in certain crafts, will probably be somewhat over the figure estimated for the force as a whole.

The next step is to consider **emergency work and definitely known peak loads.** The first item envisages work imposed on the maintenance crew by storms, heavy snowfall, freezing of lines, power failures, and the like. Even when all reasonable precautions have been taken and disasters provided against, extra patrolling, repair, and inspection must be expected. The second item of known peak loads consists of such work as overhauling of major pieces of equipment, outside painting and roof work done in good weather, plant shutdown for changes in production set-up, and, in a large plant, considerable yard maintenance on trackage, water and other service lines, etc.

PLANNING REDUCES PEAK LOADS.—Usually it will be found that by planning ahead, **peak loads can be considerably reduced,** both by preparation and by improved organization of the job itself, as illustrated by Fig. 24. If the most advantageous arrangement still imposes too great a load to complete in the desired time, the plant operating personnel should be considered as a possible source from which to secure the added manpower. Where a shutdown will be of long duration, this source should be drawn upon in any case to reduce the shutdown time.

Other methods of insuring an adequate force, without having idle men or excessive overtime work, are:

1. Adding maintenance department facilities to carry on repair work in the plant instead of sending out to service shops. A pipefitter may repair valves, salvage fittings, and make nipples. An electrician may inspect and recondition motors.

2. Carrying maintenance craftsmen on the payroll in an operating capacity, with an understanding as to alternate maintenance work which they may do.
3. Listing men who can be borrowed or engaged on call, either from friendly contractors or service shops, from among former employees, or through application lists, etc.

DEPARTMENT & EQUIPMENT	CYCLE	Week Ending																																		
		JAN				FEB				MAR.					APR.				MAY				JUNE					JULY				AUG.				
		5	12	19	26	2	9	16	23	2	9	16	23	30	6	13	20	27	4	11	18	25	1	8	15	22	29	6	13	20	27	3	10	17	24	31
Department "A"																																				
Boiler # 1	8 Weeks	●								●								●																		
2	" "			●								●								●																
3	" "					●								●								●														
4	" "	●								●								●																		
5	" "			●								●								●																
6	" "					●								●								●														
Department "B"																																				
Pumping Unit # 1506	20 Weeks						●																				●									
1507	" "		●																					●												
1508	" "								●																				●							
1509	" "																																			
Department "C"																																				
Furnace # 20	12 Weeks												●												●											
21	" "										●												●													
22	" "								●												●															
23	" "						●												●																	
24	" "				●												●																			
25	" "		●												●																					
Department "D"																																				
Generating Unit 101	15 Weeks				●										●																					
102	" "				●										●																					
103	" "					●										●																				
104	" "							●										●																		
105	" "							●										●																		
106	" "										●										●															
107	" "										●										●															

FIG. 24. Schedule for Making Heavy Repairs

Important feature is to make up **an annual program** so that men have the satisfaction of being continually and usefully employed. Otherwise men are temporarily laid off and may be lost with a lowering of group morale, or they are allowed to loaf, which is bad for discipline in the plant; or the foreman digs up some unnecessary work, which is regarded as "inefficient and wasteful."

ECONOMIC MAINTENANCE CYCLES.—Scheduling of heavy repairs may be done with the aid of a graphic or Gantt-type chart. Chamberlain (Mill & Fact., vol. 19) provides the example in Fig. 24 with the following explanation:

Certain classes of repairs should be scheduled in definite cycles to obtain the best results. Great care and good judgment must be used to determine the economical cycle for major overhauls, but once this cycle has been accomplished, a very important step has been taken toward securing superior maintenance at reasonable cost.

A street railway may find that cars should be shopped for heavy repairs every 75,000 or 100,000 miles; mileage will also be the determining factor for railroad rolling stock with different cycles for the various equipment classes, . . . unit production in automatic packaging machinery, . . . and tonnage in a steel mill. Definite periods of time may be the best gauge in some cases, while in others a combination of more than one factor may

determine the proper cycle. In any event, a detailed study by an experienced person . . . will disclose the best way to establish the cycle.

Generally speaking, only repairs involving a large amount of work should be scheduled in this manner. This practice permits the big jobs to be staggered and eliminates many peak repair loads that would otherwise occur. . . . Fig. 24 illustrates a simple visual method of keeping track of such jobs. It should be kept posted within easy view of the master mechanic or maintenance planner. It should be reasonably flexible and be revised as changes in operation are made. Actual execution of work should be marked on the chart in different colors to form a continuous record of work done as well as that planned for the future.

The **main principle** of establishing the maintenance cycle is to determine the point of maximum economy as well as the point at which hazards develop. Such points can be determined only by a study of the performance efficiency as to quantity, quality, percentage rejects, operations from machines, etc., the increasing frequency of adjustments and minor repairs, and the approach of the time when the serious failures may be expected. Detailed study of the cycle, causes of failure, and cost of major overhaul may lead to the use of improved construction elements, changes in operating practice, more specific inspection practice, and—by increasing the frequency of minor replacements—lengthening of the major cycle.

From the above discussion it is clear that maintenance program is not static, but should be in continual process of improvement. An annual review is a useful guide in directing efforts to steps promising the best results.

OPERATING COMMITTEES.—In the case of many maintenance problems, the joint concern of engineering and production departments in good upkeep leads some companies to appoint a standing committee whose duty it is to consider desired improvements and make recommendations. Such committees are useful in fostering mutual understanding and cooperation. They function most effectively when called upon to discuss definite problems, preferably with a tentative but not final proposal ready to be discussed. The usual members will be the works manager, plant engineer, superintendent, and production control supervisors, with foremen asked to attend when concerned with the proposal under consideration.

MAINTENANCE IN CONTINUOUS PROCESS INDUSTRIES.—Special considerations enter into the planning and management of maintenance in plants which necessarily are in continuous 24-hr. operation, such as blast furnaces, coke ovens, cement plants, oil refineries, where operation may continue for months without interruption:

1. Much of the maintenance work can be done only while the plant is shut down.
2. Shutdown usually puts an expensive sequence of equipment out of revenue-producing activity.
3. The plant often has tight commitments on material deliveries and on shipments, so emergency shutdowns are commercially objectionable.
4. Emergency shutdowns are a great strain on the personnel and lead to unsafe methods of operation; besides, they are more expensive than planned shutdowns.
5. Efficient disposition of the maintenance force is difficult at best Emergency conditions may demand complete disregard of cost.

These reasons make it specially desirable to plan the entire maintenance program on a **long-term basis.** Every piece of equipment should be scheduled for inspection and overhauling within safe limits of uninterrupted service. Standard methods for the overhaul should be developed, together with a careful estimate of man-hours required for the complete handling of the repair work, from taking over by the maintenance crew to release again for operation. Total man-hours for annual maintenance work should be determined, classified by crafts, and separated into work during shutdowns and work while running. Commercial schedules will indicate the annual hours during which the plant can be shut down, and the periods of the year.

Determining Size of Crew.—From man-hours required, and calendar hours available, the requisite **size of crew** can be decided upon. An effort will have to be made to reconcile the size of crew that can be kept busy on "work while running," including probably construction and alteration work, versus size of crew needed to complete the shutdown work during the available hours. Alteration work itself may be partially divided into work while running and shutdown work. Where the indicated "steady crew" is insufficient to complete the shutdown work in the available time, the peak load problem may be handled as discussed under long-term planning.

Where such a peak load exists, special attention should be given to work methods, organization, tools, and conveniences. Expensive tools and rigging may be justified less by direct labor saved than by making it feasible to work with a smaller but stabilized year-round crew. Extra care in preparation and in inspection of materials will prevent delays. Proper instructions will ensure correct performance.

SHUTDOWNS DURING MAINTENANCE WORK.—Besides the management aids on planning suggested for ordinary maintenance work, special **shutdown charts** should be made for major jobs requiring several hundred man-hours and involving several pieces of equipment with various crews. A skeleton outline of this kind of chart is shown in Fig. 25. The upper section of chart shows equipment availability and when worked on, the lower section shows disposition of crew. Such charts require considerable study but lead to fruitful results. They show up spots needing attention and reveal possibilities of reducing shutdown time, especially if discussed with master mechanic, foremen, and operating men. It has been found possible to plan so that most men were kept on their own shift during shutdown.

Planning of the shutdown should always include provision for necessary inspections, which may include items such as pumps, turbines, pipe lines serving the shutdown unit, and other equipment which can be opened for inspection only at such time. These pieces of equipment are usually not inspected as frequently as the main operating unit. Usually the best method to follow is to distribute such auxiliary inspections over the total number of annual shutdowns and make a proportionate number of auxiliary inspections at each shutdown. This practice not only makes for approximately constant off-production time, but reveals any abnormal condition more promptly than if one extra-long shutdown is made annually. Whatever such off-production time may be, once it is determined as a plant necessity, the company policy should

Time scale: A.M. 0 1 2 3 4 5 6 7 8 — Noon — 5 — 0 — 8 — Noon — 5

	Scheduled items (in time order)
No. 1 Still	1, 2, 3
No. 2 Still	←4→, 5, 6
Transfer Lines	7, 8, 9
Separator	10, 11, 12, 13
Low Pressure Tower	14, 15, 16, 17
High Pressure Tower	18, 19, 20, 21
Exchangers Sched. A	22, 23, 24, 25
Exchangers Sched. B	26, 27, 28, 29, 30, 31, 32, 33
Pumps Schedule C	34, 35, 36, 37, 38, 39
Compressor	40, 41, 42
SHIFT MEN	
Shift Foremen	← Shutting down →; General Supervision All Inspection Work and Inspection Records
Still Foremen	← Shutting down →; General Supervision All Turbining and Equipment Cleaning
1st Helper	2, 16, 41, 8-12-20
2nd Helper	

3rd Helper							
4th Helper				5			
DAY MEN							
Rigger Crew No. 1		22	35			37	25
Pipefitter Crew No. 1		10-14-18 I	23			24	I
Pipefitter Crew No. 2		26 27	28 29			30 31	32 33
Airwrench Operators		1-4-7-	11-15-19			3-9-17-21	6-13
Yardmen Nos. 1-2 / Nos. 3-4		22	35 / 23			37 / 24	25
Machinist No. 1		34	36			38	39
Machinist No. 2		I	I			I	I
Machinist No. 3		40				42	

Preparing Equipment for Maintenance Men — I: Opening Equipment for Inspection — 1-42: Regular Scheduled Maintenance Operations

FIG. 25. Schedule Arrangement for Maintenance Overhauling in a Continuous Process Plant

respect it as essential to maintenance of assets and ability to produce on schedule. Infringement by pressure from the sales or the purchasing departments should not be permitted.

Tools, Equipment, and Materials

PROVIDING TOOLS AND EQUIPMENT.—Provision of suitable tools, rigging and equipment is a major factor in economical maintenance. Specific items covering all industries obviously cannot be given here because the list would be too extensive and many devices are specialized, but a general outline may be suggested:

Job studies should be made using the general principles of time and motion analysis, but with more attention to the motions than to attempting an impractical degree of accuracy of time. Reduction in the preparation and make-ready time involving such equipment is a fruitful source of savings. Such simple steps as setting aside and tagging ropes, planking, hose, etc., used repeatedly for certain jobs save preparation time and considerable material expense. Preferred jobs on the study list will be those of the kind causing the largest maintenance expense, or peak load jobs, or jobs where the plant engineer and master mechanic request a study to straighten out instructions to men and improve maintenance procedure. The first thought should be given to reducing the frequency of the job; the minimum remaining annual expense will indicate the justifiable expenditure on tools. A survey of all the work of one craft may be made with a view to reducing man-hours to within the capacity of the given crew.

TIME- AND LABOR-SAVING DEVICES.—The following are the commoner kinds of work and the labor-saving devices which may be used on each:

Painting. Power-driven wire brushes are used for preparing surfaces; for painting, suitable paint-spraying equipment is customary, using extensions for high parts of walls to avoid scaffolding. On outside walls, a running track is often put in during construction, from which to suspend painters' and cleaners' scaffold.

Cleaning. Much cleaning work can be lightened by use of suitable hot sprays, or dipping tanks with cleaning compounds. On large floor areas, hand mopping is being replaced by power scrubbing machines. Industrial-type vacuum cleaners are essential where dust is a handicap. Good housekeeping practices simplify cleaning work.

Roof and tower work requires hoisting of materials and tools. The permanent installation of simple davits will save rigging. A portable power-winch reduces the manpower needed for hoisting and the waiting time of the crew aloft.

Portable power tools, such as chipping hammers, riveters, drills, and wrenches find wide application. The plant system of compressed air and electric lines should provide ample tapping facilities to avoid the need for extreme lengths of hose and cable.

Opening and closing of equipment, such as cylinder heads, manholds, headers, and turbines, may be expedited by the use of power wrenches. The latest type pneumatic impact wrenches will handle the

heaviest bolting work in one-quarter the time of handwork and with fewer men in the bolting crew.

Welding work usually requires both gas- and arc-welding portable units and a good supply of screens. A supply of different kinds of welding rod should be kept; building up worn parts is a great time and cost saver.

Moving or lifting heavy equipment. In an area unserviced by crane, a rail or ring above a machine to attach chain hoist, or the use of a portable crane, will lighten the job. Where a tractor is available, it can be used to tilt the machine, insert ski-shaped steel bars between machine and floor, and pull the machine to place.

Alignment of machines, shafting, etc., calls for levels, transits, and indicators adapted to needs. Tolerance and feeler gages should be provided to control allowable play.

Belt repair. A special room or crib should be arranged for belt storage, repair bench and tools, clamps and scales according to kinds and amount of belting in use.

Kind of ladders used is worth special study to minimize the work of moving them and to provide safe working conditions for one-man jobs.

Emergency repairs for reducing downtime of equipment, such as furnaces or kilns, may call for blowers, wooden sandals, inhalators, and special clothing to permit work under otherwise intolerable conditions.

The safety committee should be encouraged to keep posted on current practices and should be informed of all contemplated improvements or changes so that safe practices and safety guards or other precautions may be properly planned and instituted before operation under the new methods is started.

STORAGE AND ISSUE OF TOOLS AND EQUIPMENT.— The regulations governing maintenance tools must be as meticulously observed as those for tools and equipment used for production purposes because a large inventory is often involved. Usually the maintenance department has its own tool crib and issues and takes care of its own tool equipment under a system similar to that for production tool cribs. The tool crib must be kept locked and only the regular attendants, or possibly the responsible head of the off-shift maintenance crew, should have keys and be allowed to enter. Others must call at the window for withdrawals of equipment, or the equipment, like heavy or bulky issues of materials, may be delivered to the job.

A tool record is necessary to keep track of all implements used in maintenance. While the men will have regular tool kits, whenever they need special tools for a job they should fill out a requisition or deposit tool checks for the item. The tool is charged out by either a double check method or the McCaskey Register method, whereby the tool is charged to the workman under his name or number and also is recorded as out at its regular storage place or under its class designation (and perhaps its number) in a file system. These charges are canceled when the tool is returned in proper condition. If all right, it is replaced in its location. If dulled, it is sharpened and replaced. When worn or damaged, it is repaired under a repair order, or tag, if possible, or if beyond repair is scrapped and a replacement is secured if necessary. Tools damaged through a worker's inexcusable carelessness often are charged against

him. New tools or equipment should be inspected and approved before being placed in the tool crib.

STORAGE AND ISSUE OF MATERIALS AND SUPPLIES.—The usual arrangement is for the maintenance department to have its own storeroom, although in a small plant the production storeroom may handle maintenance stores as well. Separation is better in medium-sized and large plants. The items are thus available in a central place and at all hours for withdrawal by the maintenance man.

Materials control follows the same procedure as for production materials, and may be under the general supervision of the materials control department. Storeskeeping procedures, likewise, are the same as in the case of production items, and may be supervised, in general, by the chief storeskeeper. Actual direction and handling of the work, however, will be taken care of in the maintenance department.

Stores Record System.—The stores record system should follow the same general principles, stores grouping methods, and postings as prevail for regular stores. Usually a simple record of receipts, withdrawals, and balances of each item, and each size of item where varieties are kept, is sufficient. An order point should be established for each item regularly carried and when the quantity falls to this point, a purchase requisition should be filed with the purchasing department for replenishment. For items carried in the regular storeroom, however, replenishments can be made from regular stores with greater convenience, and without affecting the operation of the central stores control. A requisition on the regular storeroom in each case will suffice and the transfer will be recorded on the records of both departments.

All incoming materials and supplies should be regularly inspected in a place set aside for the purpose and reports of quantity, kind, and condition should be made out.

Items of materials and supplies which are not stocked must be obtained on purchase requisitions placed with the purchasing department, the same as in the case of production activities. Those left over from miscellaneous jobs are carried on unclassified stores lists.

Materials for maintenance work should be issued only upon duly authorized requisitions posted to the records and then used for cost purposes. (See previous reference to materials requisitions in this Section, page 1264.) Inventory control should be as strict as for regular production stores.

The Maintenance Storeroom.—The maintenance storeroom is under the control of a storeskeeper and, to avoid keeping men waiting, an attendant must always be on hand during working hours. At starting and quitting time, a relief man is needed to help, since the heaviest withdrawals often occur then. Also, the storeskeeper needs a substitute during lunch hour. A junior clerk is often put on the stores records and may help with the issuing. Sometimes a maintenance helper may be picked for a tour of duty in stores and to learn storeskeeping.

In the storeroom orderly arrangement is essential. Layout should follow the rules for good storing. Items carried in quantity should have separate bins. Those stored in limited amounts can be separated by bin dividers, or merely by placing them in boxes side by side on the shelves. The most frequently used items should be near the issue window, less

used items further back. Heavy or bulky items belong in lower bins or on the floor. Bar stock can be kept on racks in line with the issue window or a small sliding door, for convenience in delivery to the workmen.

The storeroom should be kept locked at all times, no one should be admitted without due authorization, and pass keys should be issued only to the regular storeskeepers and perhaps to the responsible head of the maintenance work carried on during shutdown hours, so that emergency needs may be served.

Maintenance Methods

BEST PRACTICES.—While among different manufacturing plants there is less standardization of maintenance methods than of production methods, because of the absence of design standards and the varied, intermittent, and short-duration nature of maintenance jobs, nevertheless there are best practices in rather wide use. It is advisable, therefore, to plan the procedures and operations along the lines of the most improved and efficient practices of representative companies doing the same kinds of work under much the same circumstances. At the same time, the plant engineer should see that his organization has access to the latest ways of performing maintenance work as they are described in articles in leading industrial magazines, and in pamphlets or instruction sheets gotten out by many of the manufacturers of maintenance materials and equipment. Exchange of ideas with other plants is to be recommended because the information given and received is not of a competitive nature. Good maintenance is a means of eliminating waste, an undertaking in which all plants can well afford to cooperate.

The discussion which follows must necessarily be limited to cover only the essential factors in the maintenance of buildings and equipment and cannot be given in great detail because it includes all kinds of industries operating under all sorts of conditions, and highly specific data would essentially work down to the practices of individual plants, on which there might be some logical disagreement. The information is grouped by classes of maintenance work.

BUILDINGS.—Maintenance of buildings calls for a variety of work and is best considered by parts. **Outside walls** should be inspected for cracks and openings around windows, and for disintegration of mortar joints. Necessary repairs may be effected by using cement mortar for pointing open joints, and possibly a mastic calking compound about windows. **Outside painting** of steel work, wood, sheet metal, steel sash, etc., is usually required every 2 or 3 years. **Windows** should be washed at least twice a year, once in the fall when broken panes should be repaired, defective putty replaced, and any necessary painting done.

A roof manufacturer is best qualified to repair the usual **tar and gravel and built-up roof,** having made the felts and possessing a thorough knowledge of roofs. He also has the equipment. If the roof is protected by a surety bond, the roofer responsible should in all cases be called. Heat of summer, frost action of winter months, and damage caused by severe storms, vibration, atmospheric gases or moisture may cause leaks, flashing may deteriorate, and joints of gutters open up. The **roof drainage system** requires protection against clogging with debris; screens, grating, and traps need periodic cleaning.

Foundations and footings need to be checked for settlement and imperviousness to water. The condition and safety of the building above is dependent upon them. **Floors** are of many kinds, each calling for different care. Concrete floors are repaired by patching, wood floors by replacement, and mastic floors by filling cracks or applying heat to close cracks. Prevention of accidents and facilitation of industrial truck traffic are aided by floor maintenance.

ELEVATORS.—Various kinds of elevator maintenance are offered by manufacturers. The simplest covers an ordinary examination with a resulting report to the owner on condition of apparatus. The next variety of service is examination at regular intervals, including lubrication of apparatus and adjustment of parts. Another service provides these same features and in addition the replacing, without additional charge, of small items, such as carbon and copper contacts, springs, washers, etc. A complete service covers regular examination, cleaning, lubricating, adjusting, furnishing of all parts required, making repairs, and including new ropes which may be needed during the life of the contract. This service is at a fixed cost, and assures continuous operation and safety. Emergency service is available day or night. The American Standard Safety Code for Elevators gives complete information covering construction, inspection, maintenance, and operation.

HEATING AND VENTILATING EQUIPMENT.—Periodic inspections should disclose any operating deficiencies in piping systems, radiators, valves, and traps. Minor and necessary repairs may be made as needed, but others may be postponed until the summer months, when the entire system can be given attention and made ready for the next heating season. Parts of ventilating equipment, such as fans, motors, pumps, etc., may need daily attention; other parts require inspection and adjustment less frequently. Humidifiers in use should be checked daily.

SCHEDULED MAINTENANCE OF LIGHTING EQUIPMENT.—Regularly scheduled maintenance of lighting equipment brings about economies in the use of materials, longer life of fixtures, and better illumination. Dirt on lamps and reflecting surfaces reduces illumi-

CLEANING SCHEDULE

January	February	March	April	May	June	July	August	September	October	November	December
General Office				General Office				General Office			
	Machine Shop		Assembly Section		Machine Shop		Assembly Section		Machine Shop		Assembly Section
		Ware-house, Shipping						Ware-house, Shipping			
Foundry			Foundry			Foundry			Foundry		
		Power House				Power House				Power House	
	Chemical Dept		Yard Lighting	Chemical Dept			Yard Lighting, Chemical Dept			Chemical Dept	Yard Lighting

FIG. 26. Typical Cleaning Schedule for Lighting Fixtures

nation 30% to 50%, and in many cases alters light distribution. In the East Pittsburgh plant of the Westinghouse Electric & Manufacturing Co. (Mathews, Fact. Mgt. & Maint., vol. 101), 4,000,000 sq. ft. of floor area are served on a lighting maintenance schedule shown in Fig. 26, which is adaptable to most manufacturing plants. In general, lamps are washed three times a year.

At first a central cleaning station was used. Methods studies, to establish efficient procedures, and as a basis for scheduling work and developing standard times for the application of wage incentives, brought about the design of a portable, two-compartment cleaning tank, mounted on rubber-tired wheels, in which lamp reflectors and bowls are now washed where located. One tank is used for washing and the other for rinsing. Each tank holds 20 gal. of water. The water is heated electrically by plugging a connection into the plant's 250-volt d.c. outlets. The washing tank has a motor-driven agitator to produce suds. The rinsing tank is kept at high temperature for quick drying of lamp parts.

TIME VALUES

For Cleaning Industrial Lighting Equipment

Luminaire	Means of access to luminaires	Man-hours per unit*
RLM dome reflector 100–200 watt	6-ft. stepladder	0 115
" "	8-12-ft. stepladder	0.125
" "	18–22-ft. stepladder	0 136
" 750–1500 watt	Low cranes	0.250
" 750–1500 watt	High cranes	0 263
Aluminum high bay reflector	26-ft. extension ladder	0.350
"	Low crane	0 330
"	High crane	0 345
Mirrored glass high bay reflector	26-ft. extension ladder	0.380
"	High crane	0 340
Glass steel diffuser 150–200 watt	8–12-ft. stepladder	0 312
" 150–200 watt	18-ft. ladder	0 312
" 150–200 watt	18-ft. ladder, congested area	0 312
" 150–200 watt	Stepladder in office building	0.275
" 300–500 watt	"	0.275
" 300–500 watt	18-ft. ladder, congested area	0 330
" 750–1000 watt	Stepladder in office building	0.275
" 750–1000 watt	18-ft. ladder, congested area	0 450
Mercury-incandescent combination unit	Extension ladder	0.500
Incandescent enclosing globe		
" 100–150 watt	12-ft stepladder	0.165
" 200–300 watt	12-ft. stepladder	0.190
Incandescent indirect 500 watt	8–12-ft. stepladder	0.235
†RLM fluorescent, 2 lamp, 40 watt	6-ft. stepladder, 10-ft. mounting height	0 120
†RLM fluorescent, 2 lamp, 40 watt	12-ft. stepladder, 14-ft. mounting height	0.160
"	12-ft. stepladder	0.420
Fluorescent glass enclosed, 2 lamp, 40 watt	8-ft. stepladder in offices	0.480

† Reflector wiped off only, all other items thoroughly cleaned.
* Using a two man crew.

FIG. 27. Established Time Allowances for Cleaning Lighting Equipment

Brackets covered with soft rubber tubing are clamped to the top of the ladders used in the cleaning, to hold the various lamp parts so that the workman can take up clean shades, light bowls and lamps, remove the dirty equipment, put in the clean parts and bring down and wash the others, all with one climbing of the ladder. In high bays where electric cranes operate, a safer and quicker practice is to install a working platform on top of the crane trolley to service the overhead lamps. In offices and other locations where such methods cannot be used, wash tubs and stands are taken on a small buggy to the nearest washroom and set up. Then the buggy is used to collect dirty equipment, carry it to the washroom, and deliver the cleaned parts back to the points of installation.

Extensive time studies were made to set standards for the work. The important factors studied were kinds and sizes of lamps and reflectors, and the conditions under which the work was done, whether from step ladder, extension ladder, high or low crane, or in a congested area. Flexible scheduling keeps enough work ahead so that the workmen are not limited merely to maintaining the schedules for different departments, but can increase their earnings under the incentive plan. The standard time values are given in Fig. 27.

SANITARY FACILITIES.—Maintenance of **toilets and plumbing fixtures** generally consists of proper janitor service and attention during the day. Matrons on duty in women's rest rooms will report to the proper maintenance department any fixtures out of order, and a posted bulletin in all toilets should contain the phone number of the department to be notified. Periodic inspection will be made by the maintenance department. A cleaning department will thoroughly clean all fixtures every night, and check the mechanical functioning of all faucets and equipment. **Floors of toilet rooms** should be scrubbed at these times. Locker rooms should be cleaned daily and scrubbed weekly, or oftener, as required. **Supplies** of towels, soap, and toilet paper should be replenished each day, containers being provided for soiled towels. Attractiveness and upkeep of sanitary facilities influence employees to treat them properly, minimize repairs, and promote sanitary habits and conduct.

Where employees bring lunches, insistence on deposit of all scraps and paper in closed **metal containers**, prompt clean-up of lunchroom and incineration of trash will prevent vermin nuisance.

Drinking water supply. Fountains should be of impervious, vitreous material, with jets of nonoxidizing material. A daily or semi-daily cleaning should be thorough, not only of the fixtures but also of the area immediately adjacent.

FIRE PROTECTION EQUIPMENT.—**Fire extinguishers,** most of which depend upon their effectiveness in the generation of CO_2 gas, should be recharged immediately after use, and at least once a year. Any damaged or frozen extinguishers should be reconditioned by the maker. Unlined linen **hose** deteriorates when left wet. It should be hung vertically after use or test, to drain and dry out. **Fire buckets** must be kept filled. Addition of calcium chloride, 5 lb. for each gallon of water, will protect it from freezing down to 10° below zero. **Sprinkler systems**

must be protected from freezing, and heads kept free from corrosion, paint or dust deposits. **Water supply** should be checked as to quantity and proper working of pumps and equipment. **Dry-pipe systems** must be checked for leakage of valves which may cause ice to form in pipes and prevent their functioning when needed, if the proper air pressure has not been maintained.

Yard hydrants may freeze due to leakage or poor drainage. They may be thawed out by using steam or hot water with unslaked lime added. Hydrants should be flushed and oiled about twice a year. **Fire doors and fire windows** should be inspected to see that they work freely and smoothly, and that all automatic devices are in order. Materials and equipment must not be so piled against them as to hinder proper closing.

POWER TRANSMISSION.—Motors require technical attention to check loads, temperature rise, insulation, and to note probable damage due to moisture or dust, and condition of minor parts. Lubrication and cleaning should be periodic.

Shafting needs to be checked for proper alignment, loose hanger bolts watched for, and lubrication attended to. Hopkins (Ind. Eng., vol. 87) has outlined troubles to be guarded against and the remedies suggested in the care of main drive leather belts operating from the shafting:

1. Edges start to open up. Clean, and with opened lap over pulley apply hot cement. Let stand 15 min.
2. Loose belts. Tighten.
3. Slippage. Belt may be too narrow or too light.
4. Belt not carrying load. Belt may be too narrow or too light, or surface too dry or too oily.
5. Alignment of pulleys.
6. Crooked belts. Make joint straight.
7. Disintegration. Caused by oil, water, steam, heat, or acid fumes.

An oak-tanned belt should last for from 10 to 20 years.

BELTS.—While direct-motor drive has come into wide use on machines and equipment, there is still considerable belt-driven machinery in service, and internally many machines have small V-pulley drives with round or V-belts. A **record** should be kept of each main belt drive to insure adequate inspection, maintain efficient transmission, and show the belt service life. The Tabor Manufacturing Co. instruction system for belt maintenance (Kent, Power Transmission by Leather Belting) typifies good maintenance procedure. If the **coding principle** is applied, a short symbol may describe and locate any belt without lengthy description, and will form the basis for the belt record file.

MAINTAINING TENSION IN BELTS.—New belts usually stretch to such an extent that they require tightening within 24 hours after being put up. The second tightening, as a rule, should take place 48 hours later; the third tightening at the end of the week, and another at the end of a month. **Machine or cone belts** should then be taken down and have their tension measured every 2 months, while for countershaft belts 3 to 4 months may elapse. The time at which any given belt should be tightened is determined by the entries made on the **belting record**, shown in Fig. 28.

Department: DM

Belt Symbol
L 17 C S O

BELTING

Location: 1st floor (Wing A) 30″ Lodge & Shipley Lathe
Purpose: Slow Countershaft Belt
Kind: Heavy Double Belt
Maker's Name: Schieren
Date Put in Use: 5/31
Date Taken Out:
Life of Belt:

Length Over Pulleys: 37′ 6¾″
Width: 5″
Thickness: 3/8″
Cross-Section in Sq. In.: 1.875
How Fastened: Wire laced
Belt Grease to be Used: Oil & Tallow
Belt Dressing to be Used:

Max. Velocity: 1300′
Min. Velocity: 600′
Max. Tension: 130 } in lbs.
Min. Tension: 76 }
Cost of Belt: $33.15
Cost of Maintenance:
Total Cost:

Date Retightened	Tension in Lbs.		Amount Taken Out	Date Tension Again Should be Taken	Date Cleaned and Greased	Date to be Cleaned and Greased Again	Date Dressing Put On During Service	General Remarks About Work Done on Belt, Condition of Belt, Etc.	Workman's Name	Man's Time Required to Do Work	Cost of Work
	Before Tightening	After Tightening									
5/31		130		6/1				New Belt	Ski	5	$.15
6/1	100	100	0	6/3					Ski	3	.09
6/3	70	130	1 1/4	6/7					Ski	4	.12
6/7	80	128	1 1/8	6/15					Ski	4	.12
6/15	85	125	1 1/8	7/1					Ski	5	.15
7/1	65	130	1 1/2	8/1					Ski	4	.12
8/1	95	95	0	9/1					Ski	6	.18
9/1	70	132	1 1/4	12/1					Ski	4	.12
						11/1	5/1		Ski	2	.06
12/1	85	130	1	4/1					Ski	5	.15
4/1	68	125	1 1/4	10/1					Ski	4	.12
						5/1	11/1		Ski	2	.06
10/1	60	130	1 1/4	4/1					Ski	4	.12

Fig. 28. Record of the Maintenance of a Belt

Examination of entries shown in Fig. 28 will show how the record is used to direct belt maintenance work and keep belt tensions within prescribed limits. On this special maintenance record, the top part of card is used to list all necessary data concerning belt construction and operation. In columns below entries are made of scheduled inspections and the work done on the belt. Belt details include length over pulleys as measured with a steel tape, cross section in square inches, and operating tension limits.

The instructions provide a **tension and stretch chart** similar to Fig. 29, use of which, together with a tension measuring indicator, eliminates guesswork from belt cutting and trimming.

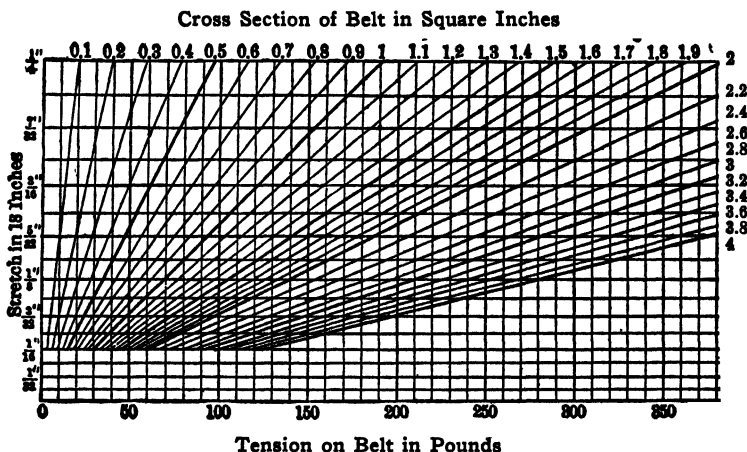



FIG. 29. Relation of Tension and Stretch for Leather Belts

Fig. 30 is a form of **belt-fixer's order** issued whenever a belt is to be retightened or a new one put up. The form of order or ticket should conform to that of other maintenance orders. A regular maintenance order form with the special belt data included on it may be used. It gives the information needed for maintenance work, including the belt symbol, which tells where the belt is located, its length as measured by the steel tape, and the operating tension limits before and after tightening. The order form also provides spaces for the belt-fixer to report the information needed for the record. After doing the work, the belt-fixer writes the necessary entries on the order and returns it to the person in charge of belt maintenance. This information is then entered on the permanent record. A decision is then made as to when the belt will next need attention and this date is marked on the record. At the same time a new belt-fixer's order is made out and filed in the tickler file to come out on a new due date.

It is essential that all the work on belts be done by a regular belt-fixer according to the instructions issued from the belting record. Machine

START FINISH DATE	ORDER NO.
LENGTH OF BELT....37'-6½".....	L 17 C S O
TENSION MAXIMUM..130#..MINIMUM..76#..	BELT SYMBOL
CLEANED AND GREASED....... GREASE USED............	
DRESSED WHILE IN USE.........DRESSING USED.........	
AMOUNT TAKEN OUT............LENGTH PUT IN..........	
LENGTH OF SPLICE...........CEMENT USED...........	
TENSION IN LBS. INDICATED BY SCALE { BEFORE TIGHTENING....... AFTER	RATE
WORKMAN'S NAME........... MAN'S NO........	COST
ENTERED IN: PAY SHEET / COST SHEET / BELT RECORD	

Fig. 30. Belt-Fixer's Work Order

hands should not be allowed, under any circumstances, to tighten or repair belts.

Cleaning and Greasing.—At periodic intervals, say 6 to 8 months, the belt-fixer, in addition to weighing the tension, should clean and grease the belt with an approved dressing. A good dressing is as follows:

A. Boiled linseed oil, 37% by measure. Tallow, 30% by measure.
B. Machine oil, 27% by measure. Beeswax, 6% by measure.

A and B are heated separately to 360° F. and mixed while hot.

PRODUCTION EQUIPMENT.—Each plant develops its own policy on maintenance of productive equipment. The common task of maintenance is the installation of machinery, aligning it and securing it to a foundation, connecting to it the power supply, and finally testing it and delivering it to the operator ready to run. Where the vendor sends a demonstrator to get the new machine into operation, the master mechanic should check over the instruction book and the machine, discuss the maintenance procedure with the demonstrator and file report on items to inspect or service and the intervals at which such work should be done.

Other common duties include:

1. **Checking of equipment** as to foundation, alignment, bearings, vibration, clearances, proper functioning of control devices, and safe condition.
2. **Replacing** of worn bearings, bushings, packing, gaskets.
3. Replacing or **repairing** worn parts; regrinding knives, rollers, wear-plates, etc.
4. **Inspection** of general condition with reports on work to be done and cost estimates as required.

The need for and extent of a machine shop for repairs will depend on the relation between quantity of work and cost of tools, availability of

outside service shops, the nature of work, emergency and the number of mechanics on the permanent maintenance staff.

POWER AND HEATING PLANT.—The power plant crew may do some maintenance work, but good practice has the stationary engineer report to the plant engineer on all equipment to insure a complete program of maintenance in the power house and throughout the manufacturing plant. The use of chemicals in **water treatment** may cause foaming and carryover of solids; appropriate inspections of turbines, traps, heating coils, etc., should be scheduled and any accumulations removed; kerosene injection while running, or as a wash when dismantled, will soften deposits on turbine blades and aid in cleaning. Extreme care should be used in **cleaning boiler tubes** with pneumatic turbines; scaling occurs much faster on a turbined tube than on new one, but careful cleaning will increase tube life. A check on the maintenance costs of the entire steam plant may indicate the advisability of installing a water-softening plant.

COMPRESSED AIR EQUIPMENT.—The compressed air system is peculiarly susceptible to abuse and overloading and is affected by the humidity of intake air. Receivers and lines should have **traps** to discharge accumulated moisture. Where drain pots are used, they should be blown out daily or oftener. **Outside air lines** may freeze in cold weather, the expansion of the air in pneumatic tools causing a drop in temperature with a deposit of moisture and consequent icing. The indicated remedy is to cool and condense the moisture in the receiver and then reheat the air. Besides periodic overhauling of the compressor, a frequent check on demand is advisable. Installation of an **auxiliary receiver** near points of surge demand may obviate the need for enlarging the line or compressor capacity.

PIPE LINES.—Continuous inspection of pipe lines will keep maintenance work at minimum. New lines should be closely watched, especially after temperature changes, to check the functioning of expansion joints, swings, and bends. Lines buried in the ground should be checked for electrolysis by earth removal to expose short sample sections. The fifth year after installation should be easily enough for the first inspection but local experience dictates the frequency of testing. **Exposed steam lines** should be insulated to the degree dictated by possible economy from reduced heat radiation and insulation kept in weatherproof condition.

Yards, grounds, and walks require continued attention to keep in safe, neat condition. Walks, runways, outdoor platforms, and stairs require the same treatment as floors.

Lubrication of Equipment

RESPONSIBILITY FOR LUBRICATION.—It is good practice to make the plant engineer responsible for all lubrication throughout plant, with authority to specify lubricants and frequency of attention, all lubrication work being done by his maintenance men. The objective should go beyond mere avoidance of trouble. Engineering attention to

the mechanisms of lubrication, power transmission losses, cost of oils and greases, cleanliness, etc., has often yielded remarkable reductions of overhead expense. Consideration should be given to:

1. Selection of lubricating mechanism.
2. Selection of lubricants.
3. Systematic lubrication at prescribed frequency.
4. Control of oil consumption.

LUBRICATING DEVICES.—If **hand oiling** is used at all, open oil holes should not be permitted; with spring-cap oil cups, oil of proper body, and oilers provided with press-button oil cans to control dispensing, even hand oiling can provide good lubrication without running oil to waste, and making greasy floors and unsightly machines, and fouling products.

Where the **simpler feed devices,** such as wick feed and bottle oilers, are used, consideration should be given to the more modern automatic varieties of such equipment, by means of which oil is continuously fed in excess, but recovered, filtered, and fed back into the system with make-up allowance. These newer models are not only better lubricators, but also may reduce oil consumption to one-half that of the lder methods.

Where **severe service** requires a constant stream of lubricant delivered by continuous pumping, the system should provide against failure, either by automatic alarm or automatic cut-in of an independent secondary source.

SELECTION OF LUBRICANTS.—Selection of lubricants is often a highly technical matter, but the following general rules are useful:

Hand oiling. If bearing conditions are such that oil is wasted, grease cups are indicated. A slight excess of grease prevents dust and grit from entering the bearing. If waste is not abnormal, heavy-bodied oil may be used, preferably compounded oil—mineral oil with about 5% to 15% fixed oil, such as acidless tallow oil, added.

Drop-feed. If specific pressure in bearing is high, a compounded oil is preferred. Straight mineral oil is satisfactory for moderate or low pressure.

Ring oiling. Since there is constant flooding, and oil is agitated, no compounded oil should be used, as the fixed oil content would cause gumming. Straight mineral oil is to be used.

Splash oiling. Oil should be light in body.

Circulation oiling. Since oil is constantly circulating, it must be adapted to temperatures reached and to withstand exposure to oxidation. It should be suitable for filtering and reuse.

In general, machinery builders' and lubrication equipment makers' recommendations should be followed. To avoid the nuisance and waste of stocking several oils of almost identical properties, a **survey of oil requirements should be made.** Suitable selection of oils to carry in stores can then be made, with steps between specifications small enough so that requirements for any case can be fairly closely matched by one of the oils stocked. Oil stores can then be managed on a regular maximum-minimum stores and purchase system, and ordering of economical quantities.

One company reports reduction by this method to 4 grades of oil stocked, instead of 14 grades accumulated by unsupervised specifications;

through this study the use of high-priced oil was also reduced. The **system of oil control** used by the A-C Sparkplug Division of General Motors is described by Kelly (Fact. Mgt. & Maint., vol. 98) and a section of the standard specifications adopted is reproduced in Fig. 31.

GENERAL LUBRICATING OILS
(Arranged in order of viscosity)

Symbol No.	Name and Description	S.A.E. No.	Applications
43522	A-150 (or A-15, was 600W) transmission oil	160	Die shoe liner pins (with S-63) Drive chains Conveyor chains Open gears Gear boxes Gas-electric truck transmissions
43524	A-80 extra-heavy crankcase oil	50	Use in general oiling *only* where bearing will not hold lighter oils. Otherwise use A-30 or, if necessary, use A-50
43517	A-50 medium-heavy crankcase oil	30	Use in general oiling if bearing will not hold A-30 Hydraulic oil above 1,500 lb. (also see P-16) Garage and test engine crankcases
43523	A-30 (or A-030 winter) medium crankcase oil	20	General oiling, ball bearings, roller bearings, and sleeve bearings (see A-80 and P-16) Motors and generators below 1,800 r.p.m. or temperature above 130° F. (see P-16) Gas-electric truck crankcases (S.A.E. 40 formerly used)
30152	P-26 heavy engine oil (low emulsion)		Air compressors (cylinder and bearings operating hot, with water contamination) Production: Air cleaner screens, Dept. 42
43509	P-16 (Dynamo) light engine oil (no emulsion)		Motors and generators above 1,800 r.p.m. and below 130° F. (see A-30 and S-13) Hydraulic oil where pressure is under 1,500 lb. (see A-50)
43519	S-13 spindle oil		Small motors above 3,600 r.p.m. (see P-16) Close-fitting bearings } All grinders High-speed spindles } All grinders

FIG. 31. Specification Sheet for General Lubricating Oils

(A section from the blueprinted specification sheet that lists all general and special oils and greases carried in general stores, and tells where to use them)

Exceptionally severe service may require a combination of a special lubricating system and a special lubricant. **Conveyors moving through baking ovens,** with temperatures so high that they destroy oils, have been successfully lubricated by following method: After the conveyor emerges from the oven, at a point where the conveyor has cooled off sufficiently (to about 400° F.), an air-operated spray lubricator is used to apply colloidal graphite suspended in carbon tetrachloride, with a

small amount of light oil and kerosene added to retard evaporation. The coating of graphite left on the moving parts provides adequate lubrication to last for several hours, the spray being applied for at least one complete revolution of the chain at a time.

FREQUENCY OF LUBRICATION.—Frequency of attention is governed by the type of oiling device and by severity of service. In **ring, bath and splash methods of oiling,** the governing factor is that oil is subject to deterioration, regardless of activity. In 6 months or less most oils form a jellylike sludge or a sediment. The prescribed treatment is to drain the oil completely, flush out the bearing with kerosene, and refill with fresh oil. Hand oiling may be required daily on high-speed work, weekly on low-speed shafting, etc. **Automatic systems,** whether gravity or force-feed, should have at least daily inspection of reservoir levels.

It is often practical to assign the care of lubrication to an electrician or to millwright helpers, as part of their inspection routine. Especially where machinery is divided into territories for maintenance men, consolidation of lubrication with maintenance makes for more intelligent care of equipment.

METHODS EMPLOYED.—Control of oil consumption begins with proper storage and distributing facilities. Oil refiners go to great trouble to provide pure products. The stores department should arrange all **oil drums in a central storage room** and equip them with suitable tapping facilities to avoid either contamination or waste. The prevailing practice in shops is to provide the oiler with a pushcart of lock-up type, in which to carry suitable oil cans plainly marked with the type oil contained, and kerosene for flushing bearings and cleaning tools. A **fire extinguisher** may be carried in clips outside the cart, available at all times. Oil will be drawn from the storeroom on requisitions. The method of charging to the operating departments should be based on the territory assigned. That is, **consumption should be measured** only for large groups as a whole, the charges being divided pro rata according to the number and size of units in each department.

Where the amount of oil consumed warrants, standards may be set for **oil budget** of the oilers. A distinction should be made between devices such as bath and ring oiling, where renewal is made on a time basis, and automatic or bottle oiling, where consumption is proportionate to activity. In the latter case plant man-hours may furnish the best gage of expected oil consumption.

DISPOSING OF USED OIL.—The method used for the disposition of dumped old oil depends on the quantity. Where the volume justifies the use of equipment, the oil may be reclaimed by appropriate treatment, separation, and filtering. Unusable waste oil should not be dumped in the sewer, unless proper oil traps are built into sewage lines. Where oil-burning equipment is in use, the best method of disposing of unusable lubricating oil is to dump it in a small covered steel tank with a false bottom and an overflow to a fuel oil tank. Sediment collecting on the false bottom is removed periodically and burned in an incinerator, with unreclaimable greasy rags. **Oily waste and rags** are serious fire hazards and should be collected and cleaned or destroyed as soon as possible. They are subject to spontaneous combustion.

Good Housekeeping

ORDER, NEATNESS, AND CLEANLINESS.—Good workmanship, high production, sound personnel relations, and final quality of product are so definitely dependent on order, neatness, and cleanliness in the plant that the production engineer finds himself a leading crusader for good housekeeping. While department foremen are supposed to instruct and supervise their workers in keeping departments and workplaces orderly, neat, and clean, there are many factors which require more attention and service than can be given in the normal course of shop operation. Some equipment and certain facilities are not in direct personal use by individual workers and therefore no one is directly responsible for their care. The accompanying check list includes most such items, with an indication of the procedure to follow to bring about proper conditions.

In some cases—toilets and washrooms, drinking fountain, safety equipment, etc.—periodic inspection and minor attention may be already in effect. There are likewise scheduled times for cleaning of floors, washing of windows, cleaning and check-up of lighting systems, in many plants. Some of the work is done by janitors who may report to an operating supervisor in the regular line organization. But the plant engineering department, by the very nature of its duties, is called upon to maintain so many of the plant facilities that considerable of the actual good housekeeping work comes under its regular operations. If there is a possibility that the plant engineer can take over the whole responsibility and handle it more successfully than any other available executive, the work should be made a part of his regular assignment.

A GOOD HOUSEKEEPING COMMITTEE.—So much depends upon the backing of management and the authority needed in such efforts, there are so many chances of friction between operating department heads, production engineers, and plant engineers on the matters of local order and cleanliness, and the workers so often do not spontaneously respond to good housekeeping instructions, that frequently the best way to handle the undertaking is to set up for the purpose some permanent, and perhaps rotative, committee composed of representatives of all groups, including operating departments, production control, plant engineering, the office, and top management. The work of such a committee is most successfully carried on under plans similar to those followed in suggestion systems. It is very necessary to have the committee consist only of enthusiastic, live, tactful, persistent, patient, forward-looking, and realistic men, with certain leadership qualities. "Die-hards" and those satisfied to run in ruts dampen the interest and kill the effort.

METHODS FOR ORGANIZING THE WORK.—The good housekeeping drive must be ably planned, advertised widely on bulletin boards, in plant papers, and perhaps by circulars or cards in payroll envelopes. It should begin by the issuing of explanatory sheets indicating what to do to clean up the departments and set them in order. A short period should then be allowed to lapse to give time for each department to set its house in order. Then the committee should make

a full inspection, perhaps awarding two or three prizes to the departments which—considering their limitations and the nature of the work they have done—show the best results, all limitations taken into account.

INSPECTIONS AND FOLLOW-UP.—After this, the inspections should be periodic, announced in advance, and followed by published reports or announcements, to keep the laggards in line. Awards then can be made over periods, say every quarter. The plant manager must periodically see to it that the committee stays live, that its activities are backed up by proper enforcement to get noncooperative foremen or workers into line. It seems that once a year a special campaign should be run prior to one of the inspection periods. Memorandums to the foremen and supervisors will keep them informed of matters which have escaped their attention. The committee must be prepared whenever necessary to work out detailed plans for correcting bad conditions and for regularly maintaining cleanliness and order in spots which give particular trouble. It should therefore have access to all the technical facilities in the plant, but as far as possible should see that all the work done is in and by the departments where the wrong conditions exist. Otherwise the responsibility will be passed on to the good housekeeping committee or the maintenance department, when the latter's job may be one of upkeep and repairs rather than order and cleanliness in manufacturing operations.

Key slogans in any such work are:

"A place for everything and everything in its place."
"A clean and orderly plant is a safe plant; a safe plant keeps orderly and clean."

Other crisp and printed slogans can be easily developed (perhaps with awards to suggestions) in any plant where good housekeeping is made a regular part of plant operation.

ADVANTAGES OF GOOD HOUSEKEEPING.—Among the important advantages of good housekeeping are:

1. Production rate increased because of the orderly, businesslike condition of departments, removal of obstacles to production, etc.
2. Production control made easier. Materials and parts do not get lost or mixed. Speed of removal of work and less banking of rough or processed materials are corollaries of good order. It is easier and quicker to check operations and get data for records.
3. Inspection work takes on a high character. Quality control of work follows order and cleanliness control of conditions.
4. Materials and parts conserved and salvaged. All unused materials or parts, spoiled work, scrap, etc., are removed to proper places.
5. Time saved. Search for tools, work, etc., eliminated. Workers have more room to operate freely. No time lost in clean-ups to get space in which to work.
6. Floor areas are cleared for production instead of being littered with rubbish or crowded with unnecessary banks of work.
7. Maintenance and repair work facilitated. Repairmen can get at machines, do not have to clean them of dirt and grease, have room in which to do the work.
8. Safety protection made more certain. Elimination of crowded quarters makes machine operation safer. Clear, clean floors cut down stumbling and tripping, and slipping on greasy or oily spots. Clear

traffic aisles reduce collisions of trucks, running into workers, knocking over piled materials, etc.
9. Fire protection improved. Fire hazards and spontaneous combustion are removed. Areas are cleared for quick exit, and for room to get at and fight any fires. Carelessness with matches is avoided.
10. Cleaning costs reduced. Janitors can do their work faster and better. It is cheaper to keep dirt down than to remove long-time accumulations.
11. Morale is heightened. Workers used to decent conditions at home become more interested in the plant when cleanliness and order are enforced.

There are no disadvantages in cleanliness and orderliness. No arguments can be advanced against a program of this kind which cannot be disproved by any executive or production engineer who has put methods of plant good housekeeping into operation. Neither merit nor profit attaches to being dirty or disorderly and no excuse exists for the toleration of such conditions. If they exist, they are a direct reflection on the character of the plant management.

CHECK LIST FOR MAINTAINING AN ORDERLY PLANT.—The points upon which continued orderliness and neatness in the plant are maintained may be summarized according to the following typical check list. Modifications may be made to fit the list to the needs of any particular plant.

Walls, Windows, Ceilings.

1. Walls should not be used for storage of materials, such as pipe, small fittings, wire, cord or string, wiping rags, etc.
2. Unnecessary bulletin boards, production boards, work order or time ticket clips, charts, pictures, etc., should be taken down. Notices and information should go on bulletin boards, not on the wall proper.
3. In places where dusty or dirty operations are done, the walls should be cleaned several times a year. Vacuum cleaning is preferable to brushing.
4. Shop as well as office walls in many cases should be painted when cleaning no longer removes the dirt, or when illumination and work visibility can thus be improved.
5. Storage of items along the ceiling is unsightly and dangerous. Ceilings, like walls, should be cleaned, and painted when badly soiled. Better work illumination results.

Aisles, Exits, Stairways.

1. Traffic lines painted along aisles will keep them clear of work banks, as well as prevent accidents by marking off the work areas.
2. Exits and surroundings should be kept clean of all banks of work so that traffic of trucks and workers will not be impeded.
3. Doors get dirty from contact with trucks, clothing, and hands. They should be washed occasionally and frequently touched up, at least, with paint.
4. Stairways must be kept clear of all materials, equipment, rubbish and dirt. They need daily cleaning. If corners are painted white, they will be kept free from papers, dirt, tobacco juice, chewing gum, and other unsightliness.

Floors.

1. Oil, waste-material, paint, dirt, and other accumulations under machines can be caught in pans or on sheet metal, scrap fabric or paper which

can be regularly removed and replaced. Oil-soaked floors cause accidents and are added fire risks.

2. Painted lines will mark off machine and work areas to prevent cluttering and congesting them with materials.

Toilets, Washrooms, Locker Rooms, Showers.

1. Daily cleanings and rubbish removal are imperative to good housekeeping. Floors should be washed. Frequent painting is of definite aid in good sanitation.

2. Rubbish can, receptacles for used paper towels, neat racks for wet towels and cloth, and other facilities aid in cleanliness.

3. Daily use of inoffensive disinfectants keeps such rooms germ and vermin free.

4. Good light and ventilation add to the cleanliness.

5. Soap dispensers are cleaner and more economical than soap cakes.

Drinking Fountains, Beverage Dispensers.

1. Drinking fountains should be washed daily.

2. Signs should be put up, if necessary, to discourage use of the fountains as depositories for chewing gum, or as cuspidors.

3. Dispensers of bottled or bulk beverages should be replenished regularly and kept clean. If the beverage is in bulk form, the unit should be washed off with hot water periodically.

4. For bottled items, receptacles should be provided for empties and caps. Otherwise they will be thrown around the floor.

Manufacturing Equipment.

1. Dirt and oil accumulations should be removed from machines daily, in most cases, sometimes several times a day, if the work must be kept clean.

2. Painting is necessary on many kinds of equipment, not only for reasons of preservation and good illumination but also to keep the factory clean.

3. Chips from metal-working, cuttings from fabrics, and other collections should be dumped directly into containers, if possible, rather than brushed off to the floor.

4. Tools, gages, etc., should not be left on machines when work is completed. Finished or unfinished parts should be kept in receptacles, not stored on machines.

5. If the machines have highly burnished or plated parts, these should be cleaned occasionally with suitable polishes.

6. Work tables on textile and other machines should be cleaned and waxed periodically with proper polishes.

General Equipment.

1. Tables needed for manufacturing operations should be kept free from collections of finished or unfinished parts, scrap, tools, rubbish, etc. They also require periodic cleaning and polishing.

2. Racks for work should not have clothing, rags, equipment, or odds and ends hung on them.

3. Benches often accumulate all kinds of tools and accessory items used in the department, spare parts, bolts and nuts, odds and ends of material, etc., as well as rags, papers and old records, bottles, and all sorts of rubbish. If a worker thus "keeps the pig in the parlor," his work and his methods will be similarly affected. This matter of good housekeeping is the place where it is often hardest to bring about improvements, for the employee obviously must have some place to keep certain personal belongings. Examples of order and cleanliness in benches, and pointed propa-

ganda will cure much of the trouble and release considerable accumulations of materials and even tools and instruments.

4. Cabinets, like benches, collect all sorts of items which do not belong in them. Signs on the cabinets marked something like this, "This cabinet is for .... only. Please keep it in order," and occasional inspection, get rid of the junk and reserve the space for proper use.

Safety Installations.

1. Besides regular inspection for service and to see whether they are in use, safety installations need attention for condition and cleanliness. Guards draped with rags, and other carelessness and untidiness of safety devices discourage their use.

Fire Protection.

1. Fire-fighting equipment should be kept clear of all materials, work in process, boxes and packing cases, unused machinery or any other obstacles to immediate access. Hand extinguishers, fire pails, axes, fire hose, lanterns, etc., should be kept neat and in order, immediately available in proper places, as well as undergoing periodic inspection for serious condition.

2. All such items should be cleaned and kept polished or painted. City fire departments find that preparedness is increased by the well-known meticulous care used to keep equipment clean, bright, polished and painted. The term "ship-shape" for cleanliness and orderliness typifies the importance attached to such factors as preparedness measures, in naval and marine services.

Unused Manufacturing Equipment, Tools, Etc.

1. All equipment which is obsolete or worn out should at least be removed from the manufacturing floor, and stored in a central place, marked with an identification tag stating its name, number, make, department used in, date and reason of removal, intended disposal, and perhaps its estimated value. The removal record should be noted on the equipment card, so that the machine can be replaced in use if needed later. If the equipment is of no further use, it should be sold, or broken up for scrap. Such a plan enables departments to be kept in better order and to gain more floor area for rearrangement of processes. Also the departments can be more easily kept clean. Equipment should never be stored within the department, in passageways, under stairs, or in odd spots where there happens to be vacant space.

2. Broken, worn, and obsolete tools should not be allowed to collect in or around workplaces, where they are in the way and indicate lack of order. They should be removed for repair or scrapping.

Salvage Items.

1. Paper which can be reused should be collected in regular containers provided for the purpose. Scrap paper, if possible kept sorted at point of origin, can be put into other containers and collected.

2. Boxes, crates, cartons, and other packing containers which can be reused should be promptly collected and removed to storage in a reclaiming department. The rubbish trucks can make the collections and deliveries.

3. Used rags and waste may be reclaimed by washing and should be removed promptly for this purpose because they constitute fire hazards.

4. Discarded materials and spoiled work should be taken over by the salvage department daily to keep operating departments free from disorder, and also to control and account for the causes and costs of these losses. Spoiled work should have a release from the foreman or inspector.

Scrap Removal.

1. Regular scrap items, such as chips, borings, or other waste materials from operations can be collected, if possible, in boxes or pans right at points of origin, or can be periodically cleaned up and taken to a department receptacle. The different items should be kept separated, particularly different kinds of metals.

Rubbish and Garbage Removal.

1. Floor sweepings consisting only of dirt, miscellaneous rubbish such as small quantities of sawdust, rags too soiled to reclaim, odds and ends of twisted or broken nails, or other small items, and dirty and soiled paper and cartons should be collected in waste cans instead of accumulating under machines or benches, or in some corner. If employees eat their lunches in the departments or buy candy, sandwiches, etc., from traveling venders, the refuse should be at once deposited in cans to prevent attracting vermin. These cans should be emptied into traveling trash bins twice daily. The cans should be kept clean and in good condition. Periodically they should be washed and repainted.

Storage Areas.

1. In operating departments white lines painted on floors will keep work banks in proper places at machines.

2. Marking off floor areas in storerooms for items which must be kept on the floor, likewise will keep these items within proper boundaries and be conducive to orderly piling and regular contour of storage piles.

3. Proper storage layout, with like items together, and regular stacking on shelves will facilitate locating and issuing stores, making physical checks, adding new stock, etc.

4. Orderly storage, with everything neatly in its place, will avoid loss of materials, reordering items already on order, ordering when stocks are already high, etc.

Plant Yard.

1. If for no other reason than the resulting advertising value and public goodwill, plant yards visible from railroads, highways, and nearby manufacturing or residential areas should be kept neat, orderly, and free from trash, rubbish, and dumps. Even piles of coal, sand, clay, and other bulk materials can be kept trimmed, with the contents all within allotted areas. Yard storage areas, therefore, should be given as much attention as inside areas.

2. Tracks, walks, and roadways must be kept free from obstacles, rubbish, and growths of weeds and coarse grass. The limits should be neatly marked. Traffic and clearance lines also are often effective and are good safety precautions.

3. Outsides of buildings should be kept repaired, painted, if necessary, and clean. The effects of such attention and yard cleanliness are reflected in the higher production and better morale of workers. Company orderliness adds prestige to employees in the plant.

General Cleanliness and Order.

1. Aside from isolated attention to separate factors, there are general matters of order and cleanliness which require attention. In offices, accumulations of unnecessary or unused papers and other items should be thrown out, or stored in proper cabinets or files. Scraps should be thrown into waste baskets, not on the floor.

2. In shop and headquarters offices, mats are sometimes needed to remove dirt from the shoes of men who come in from the yard, foundries, etc.

3. Where smoking and tobacco chewing are permitted, cuspidors should be provided. Small rubber or linoleum mats will catch the "near misses." Regular cleaning is imperative.

4. All bulletin boards should be kept in good trim. When notices get old they should be removed. It is better to have separate boards for permanent notices, or put such items into employee manuals. Current notices on other boards will then be read. Posting should be neatly prepared and squared with the edges of the board. Prompt removal of past events keeps the board orderly and up to date.

5. Items of cleanliness and order relating to window cleaning, lighting-fixture cleaning, and schedules for the care of toilets, washrooms, locker rooms, drinking fountains, etc., are covered under the paragraphs of this Section dealing with Maintenance Methods.

Depreciation of Buildings and Equipment

TWO PHASES OF DEPRECIATION.—A discussion of plant maintenance brings up the question of depreciation, which has two phases—**engineering and accounting.** The accounting phase will not be discussed here, except to indicate the different methods under which depreciation charges are written off. The production engineer relies on the care taken to arrest depreciation so that he can plan operations, schedule multishift and overtime work when necessary, and otherwise carry on his activities with the assurance that decrepitude of buildings, equipment, and machinery will not wreck his well-laid-out programs. The plant engineer, likewise, should be familiar with the factor of depreciation because he collects and records data on additions, removals, repairs and replacements and this information is used by the accounting department in making its postings and preparing reports and statements. Moreover, useful life of buildings, services and equipment is dependent partly upon the nature and quality of inspection, adjustment, cleaning or lubrication, repair and general maintenance work done, all of which should be duly recorded. Finally, depreciation expresses the transfer of value from plant and equipment used to the product manufactured. Thus it becomes an element in the cost of production, which will hence go up or down according to the quality of the maintenance work carried on.

The **engineering factors of depreciation** are concerned with the kinds, causes and arrestants of deterioration. Unless the plant engineer has a clear conception of these matters he is to that extent limited in his attempts to reduce the decline in condition and usefulness of plant and equipment. In addition, the plant engineer is often called upon to **appraise equipment** and determine its **life expectancy.**

CAUSES OF DEPRECIATION.—The causes of depreciation are classified in Fig. 32 (Kester, Advanced Accounting). The terms used are largely self-defining or are explained by the details given.

It will be noted that some of the **causes are partly preventable** and it is one of the plant engineer's functions to develop and apply means to remove or lessen such causes. Carelessness and the neglect of cautions against accidents to equipment are common origins of excessive depreciation. Other causes are unavoidable but may be slowed in action by regular inspection and repairs to lengthen the life periods of the

items affected. Examples are the rusting of ferrous materials and the rotting of wood, both of which can be slowed down by painting at proper intervals. Still other causes are natural wastes from use, but means to prevent excessive or unwarranted use of the items will make them last for longer periods. Light bulbs, in little used areas, for example, will have a longer cycle of life if the current is switched off whenever the lights are not needed in the locality. Some of these measures depend

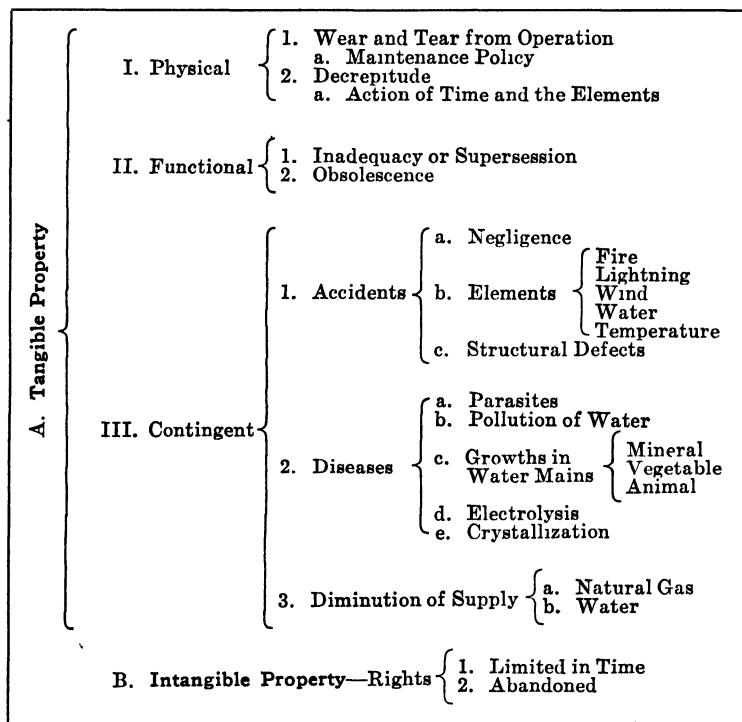



FIG. 32. Classification of the Causes of Depreciation

upon the cooperation of operating departments but the maintenance department must take the lead in setting them up and checking upon their observance.

In **design,** likewise, provisions can be made against excessive physical depreciation or emergency damage. Building walls or roadways near streams can be protected by rip-rap to prevent undermining. In flood areas, buildings should have no basements. In areas infested with termites, wood should be omitted from all construction near the ground. High, slender structures need bracing against the wind and protection

against lightning. Building floors must be designed with a factor of safety for impact as well as static floor loads. Fire protection equipment—hydrants, sprinklers, hose lines, extinguishers, fire buckets—are needed at points where they will be effective in quickly putting out sudden fires. Power equipment requires protective devices, such as lightning arresters, circuit breakers, fuses, and overload cut-offs. While insurance protection of various kinds may furnish funds toward replacing losses from accidents, fires, disruptions in use and occupancy, and other hazards, it should by no means in any way take the place of good maintenance. There is probably never full recovery because of unforeseen losses from failure to cover the risks properly, shutdowns of production, and the expense of adjustments and claim settlements are not often offset in addition to the direct damage or loss suffered.

Not even good maintenance, however, can always lengthen the **profitable life of equipment.** Machine tools, for example, may cease to be economically useful long before the end of their physical life for satisfactory operation has been reached. Obsolescence caused by the development of better machines, or because of a change in markets which forces the alteration or dropping of products, may force the sale or scrapping of perfectly good equipment for which a plant no longer has any use. Buildings themselves may become obsolete through changes brought about by technological or business trends.

ARRESTANTS OF DEPRECIATION.—Certain factors tend to lessen, minimize, or arrest depreciation and must be taken into consideration in determining the life expectancy of physical property.

1. Care and attention given to plant and equipment by operating personnel.
2. Maintenance and repair policy and practice.
3. Changes, alterations, and improvements to prevent obsolescence. Low personnel turnover, especially if aided by a training program and fixed responsibilities, prolongs life of equipment. Planned inspections and rigorous maintenance have a similar effect. Continuous improvements may prevent much hidden obsolescence. Hence such factors must be given full consideration in establishing and rechecking estimates of life expectancy and depreciation rates.

LIFE EXPECTANCY OF PHYSICAL PROPERTY.—Tables have been developed giving the life expectancy of many items of physical property—buildings, building elements, manufacturing and power equipment, etc.—based upon experiential data. The varying conditions under which these physical items are used, and the fact that the data have been developed from individual experience cases often involving personal opinions, mean that wide ranges exist between maximum and minimum average life expectancies. Kurtz, however (Life Expectancy of Physical Property), concludes that the relation between certain life characteristics of physical property are of the nature of laws which permit of a scientific determination of the life expectancy of equipment and its attending problems; and that the observations regarding the life of physical property can be classed as natural phenomena.

EFFECT OF MULTISHIFT OPERATION ON LIFE EXPECTANCY.—Most authorities agree that increased intensity of use accelerates structural damage beyond the point of economic repair,

especially as to moving parts. Further, by increasing the impact of demand for new equipment and multiplying the gains to be made by installing improved machinery, the process of obsolescence is hastened. Earlier removal of old units necessarily reduces average equipment life. Older buildings are frequently unsuited for the installation of new equipment and modernized processes. Causes tending to increase wear-and-tear per hour, especially prevalent under multishift operation, are:

1. Divided responsibility.
2. Strenuous use.
3. Interrupted and inadequate maintenance.
4. Frequent changes in operators.
5. Untrained and inexperienced operators.
6. Inadequate supervision.

For estimating reduced life expectancy under multishift operation, the **conversion table** in Fig. 33 is suggested as a guide. It assumes reasonable added current maintenance, but no specially expected inadequacy and no rebuilding.

Normal 1-Shift Average Life, Years	Under Multishift Operation					
	Buildings and Equipment Without Moving Parts		Machinery			
			Slow-Moving; Infrequently Changed Arrangement		High-Speed, Accurate Quality Requirements	
	2-Shift	3-Shift	2-Shift	3-Shift	2-Shift	3-Shift
50	40	35	—	—	—	—
40	35	30	—	—	—	—
30	25	20	—	—	—	—
25	20	18	—	—	—	—
20	17	14	13	10	11	9
17	—	—	12	9	10	8
15	—	—	11	8	9	7
13	—	—	10	7	8	6
10	—	—	8	6	7	5
8	—	—	7	5	6	4

FIG. 33. Life Expectancy of Buildings and Equipment Under Multishift Operation

While the data in Fig. 33 represent the consensus of several authorities, in important cases, or in case of doubt, it is advisable to make a **special evaluation.** After the determination of normal 1-shift conditions as to the effect on economic life of wear and tear, obsolescence, and inadequacy, each of these factors may then be adjusted to conform to expected conditions. The shortest life thus determined will be the adjusted life expectancy.

TREATMENT OF OBSOLESCENCE.—Paton (Accountants' Handbook) presents the following principal alternatives to an effort to cover obsolescence (and similar factors) through systematic charges to revenue for all or a part of the life of the property unit involved:

1. Recognition of loss as expense when property is eliminated and fact and amount of obsolescence become apparent.
2. Same as (1), except that the loss is charged to net income or surplus.

3. Earmarking of a section of surplus as a reserve for contingencies, followed by treatment as in (2).
4. Treating loss as a special deferred charge to be absorbed as early as possible against future revenues.
5. Capitalization of loss as part of cost of property replacing unit eliminated.

The serious flaw in the treatment of obsolescence as the "cost of future revenue" is illustrated by following example:

Assume that equipment installed at a cost of $10,000 was at the time of its purchase the most efficient available. Its life was assumed as 10 years and a $1,000 depreciation reserve was accumulated annually. Five years later a new type of equipment made the original completely obsolete, with a write-off of $5,000 necessary.

The crux of the matter is whether the original installation was needed to produce output for the 5 years until the new machinery was offered. Either the installation was excessive or the obsolescence factor was misjudged and the depreciation rate insufficient. In either case the manufacturing loss was accumulated in 5 years of operating history. To charge a past error against future operations can fatally stifle an enterprise, or result in relinquishing an essentially profitable field to unencumbered competition. However, the write-off due to obsolescence may be used to justify a more conservative life expectancy of future acquisitions.

The extreme view that coming changes in demand, legislation, new equipment, and the like should be disregarded until actually an accomplished fact is not tenable under modern conditions. While accurate prediction of obsolescence over long periods is not feasible, there are available indications.

1. New developments in general are well reported.
2. Legislation, to be successful, must be preceded by marshaling of support over a considerable period.
3. Development of specific new equipment tends to be a cooperative enterprise of some machine builder and users. Inquiries by a machine builder indicate initiation of development work.
4. Rate of introduction of new machinery in a given field is often a predictable factor.
5. In the automotive field, forecasting of developments has reached the stage of organized published information. Absence of published data in other fields does not make the development any less a fact to be considered. Details may be less readily available, but the general trend is ascertainable.

DETERMINATION OF DEGREE OF OBSOLETENESS.— Leerburger (Estimated Actual Depreciation) discusses at length the possible measurement of the degree to which obsolescence has reduced the value of equipment. While his treatment is primarily related to public utility property, a reference to the principles followed may be generally useful:

1. In **evaluating obsoleteness,** all other factors of depreciation are neglected. The basic assumption is comparison between old equipment in new and undeteriorated condition and the most modern equipment.

2. **"This equipment is partially obsolete"** means that a new type of equipment installed in its place would effect a certain annual reduction in the algebraic sum of fixed charges plus operating expense.

3. These **potential savings** may be summarized to a "present worth" basis. The estimate of present worth will depend on two factors, rate

of return and term of years. In the utility field, rate of return is prescribed by regulatory bodies within a fairly narrow range of 6% to 8%, hence selection of the period to extend the savings is the dominant factor. Since newly installed equipment will itself be superseded, it is not safe to assume that savings will run in perpetuity. The probable time of complete obsolescence will usually range from 15 to 30 years.

4. **Present worth** is that sum which, placed at compound interest, will permit the payment of a fixed sum at uniform intervals of time. Lang and Schlauch (in Mathematics of Business and Finance, and in Selected Tables) present the concept of present value of annuities mathematically. The tabulation in Fig. 34, adapted from Leerburger, shows the variations resulting from the different assumptions. As an example, if $7.36 is put aside at 6% interest compounded yearly, and $1 is taken out at the end of each year for 10 years, the fund will be reduced to zero.

Assumed Elapsed Time in Years	Multipliers Corresponding to Assumed Time Rates of Return or Interest		
	6%	7%	8%
10	7.36	7.02	6.71
15	9.71	9.11	8.56
20	11.47	10.59	9.82
25	12.78	11.65	10.67
Infinite	16.67	14.29	12.50

FIG. 34. Present Worth Multipliers for Various Rates of Interest

Using present worth multiplier (M) and symbols C and C_e for construction cost, actual for old equipment and estimated for new type, O and O_e for operating and fixed charge expense, actual and estimated, Leerburger offers following formula for estimating obsoleteness:

$$\text{Percentage of obsoleteness} = \frac{C - C_e + M\ (O - O_e)}{C} \times 100$$

The $M\ (O - O_e)$ portion of the numerator is usually a positive factor, while the $C - C_e$ portion is usually, but not necessarily, negative. If total of the numerator is negative, no over-all savings would result from the change indicating absence of obsolescence. If total is equal to or greater than C, the equipment is completely obsolete; if less than C, the formula will give the percentage of obsoleteness.

As an example, Leerburger gives figures on an existing power plant system, compared with a proposed new construction of equal capacity but improved operating characteristics:

	Existing Plant	New Type Plant
Annual fuel costs	$ 2,715,000	$ 1,764,000
Other operating expenses	1,514,000	1,231,000
Taxes and insurance	552,000	552,000
Total annual expense	$ 4,781,000	$ 3,547,000
Construction costs	$47,237,000	$50,600,000

Assuming a life of 25 years and a return of 7%, the multiplier (see Fig. 34) will be 11.65.

Percentage of obsoleteness =

$$\frac{(47{,}237{,}000 - 50{,}600{,}000) + 11.65\,(4{,}781{,}000 - 3{,}547{,}000)}{47{,}237{,}000} \times 100$$

$$= 23.3\%$$

The above method, while primarily for valuation of utility property, may be useful in the appraisal of obsolescence in the case of other plants and equipment. In each case care must be taken to justify the figure taken as the life period to complete obsolescence.

OBSOLESCENCE FROM LOSS OF ECONOMIC USE.—Where obsolescence occurs from loss of economic use, it is usually due to shrinkage in consumer demand for output of the equipment. It may be evaluated on basis of operating income. For this purpose, it is necessary to evaluate normal operating income under the conditions when installed, versus operating income under the existing conditions of assumed reduced demands, making allowance for cost of intermittent operation, space occupied, etc. In considering a decision to dismantle obsolescent equipment where demand still exists but at much reduced level, customer reaction on other business should be checked. If retention of an item of production is needed to maintain an activity level for other equipment, a conservative estimate of fixed charges recovered through such retained "other business" may justifiably be added to operating income in estimating the degree of obsoleteness.

Depreciation Bases

DEPRECIATION BASE.—The depreciation base is "the actual or adjusted initial value of the asset unit, determined to be subject to periodic diminution and eventual complete write-off." There are four principal depreciation bases applying to industrial property:

1. Cost, either entire, or adjusted by adding the resale value minus the removal charges.
2. Cost plus maintenance (estimated) minus net salvage value.
3. Replacement of reproduction cost.
4. Present value (usually determined by appraisal).

The derivation of the depreciation base is shown in Fig. 35, which indicates the elements of cost, the gross and net investments and the portion of money which has to be earned back by depreciation charges.

COST, ENTIRE OR ADJUSTED, BASIS.—Under the cost, entire or adjusted, basis the calculations are simple. Useful life, resale value, and cost of removal must be estimated. In many cases, especially of heavy equipment, the resale value is less than the removal charge, giving a negative net resale value, since such equipment is frequently retired because of loss of utility, inadequacy, etc., and not because of wear and tear. Thus, companies insist that the savings or earnings from a piece of equipment must repay its original installed cost several years before the depreciation accumulation for its retirement equals this cost.

CATALOG INVESTMENT
PURCHASE PRICE OR PRICE OF CONSTRUCTION
UNCATALOGED INVESTMENT
COST OF TRANSPORTATION
INSTALLATION FOUNDATION (WIRING, PIPING......)
SUPPLEMENTARY, AUXILIARY EQUIPMENT (SHAFTS, MOTORS........)
COST OF ACCESSORIES (STAND, TOOLS, JIGS, FIXTURES)
INCIDENTAL COSTS, SUCH AS TESTING AFTER INSTALLATION, FIRST INSTRUCTION
GROSS INITIAL INVESTMENT (CHARGED TO ASSETS)
CHARGED TO CURRENT EXPENSE
TOTAL MONETARY REQUIREMENT
RESALE VALUE
NET RESALE VALUE
COST OF REMOVAL
NET INVESTMENT
NET SALVAGE VALUE
PORTION OF MONEY WHICH HAS TO BE EARNED BACK FROM OPERATION OR SAVINGS THROUGH REPLACEMENT

FIG. 35. Derivation of the Depreciation Base

COST-PLUS-MAINTENANCE BASIS.—The cost-plus-maintenance method has the theoretical merit of recognizing that major repair expense, required at widespread intervals to attain expected long life, should be evenly distributed. But the method is unsuitable for tax purposes and it is almost impossible accurately to estimate the total maintenance during the complete life of the equipment and the ultimate salvage value. Annual charges obtained by spreading a questionable total over an uncertain life period do not command confidence.

Representative practice is to **handle maintenance charges separately,** with provisions for accruals when necessary. Separation of total plant maintenance into items for each depreciable unit permits assembly of a total maintenance and depreciation annual charge per unit which can be defended.

REPLACEMENT OR REPRODUCTION COST BASIS.—The method of basing depreciation charges on estimated cost of replacement or reproducing depreciable unit, rather than on actual cost, has the advantage that the real intent of depreciation, which is to provide for the ultimate replacement of the property when it is worn out, obsolete, or otherwise rendered useless, is achieved. Furthermore, under this plan overhead charges are not burdened with an amount in excess of what is necessary to provide for the current value of the equipment.

The main arguments in support of replacement charges are that the replacement cost basis:

1. Provides means to maintain operating capacity of industrial plant out of current revenues.

2. Provides means to influence selling cost primarily by replacement costs which reflect current operating conditions.
3. Is more appropriate than acquisition cost basis for purposes of financing, insuring, and the like.

The principal objections to replacement cost charges are that:

1. Actual cost should be basis of all charges to operation, not an estimated cost.
2. Depreciation charges when based on replacement costs require continuous adjustment of property accounts.
3. Depreciation charges based on replacement costs have no standing for income tax purposes.

Present Value Basis.—This basis, also called the fair market value basis, is required under income tax rules for a number of special cases, not many of which concern industrial property. The principal case where this basis applies is property acquired prior to March 1, 1913, and property acquired by gift or transfer in trust after December 31, 1920.

DETERMINATION OF DEPRECIATION.—It is impossible to make rules of depreciation for various kinds of plants, machines, or units that will apply in all cases, or even in many cases, as the various factors entering into and causing depreciation will vary in every individual case. Neither is it possible or wise to endeavor to determine depreciation for a plant as a whole, as variations in factors as applied to different classes of fixed assets make the situation too complex to be dealt with as an entity. Under these circumstances, it becomes necessary to divide the plant into various classifications, such as:

Land
Buildings
Building Equipment
Power Machinery
Manufacturing Machinery
Patterns and Dies
Etc.

After these classifications have been determined, items falling under each classification should be further subdivided. For instance, buildings should be classed as:

Frame Buildings
Sheet Iron Buildings
Brick and Mill Construction
Brick and Reinforced Concrete
Etc.

Or manufacturing machinery as:

Lathes
Drills
Punch Presses
Spindles
Looms
Etc.

After the various items of assets have been classified, then each item should receive careful consideration of all of the factors entering into or affecting depreciation, and a rate determined upon, necessary to give as accurate an estimate as possible of the depreciation that will accrue during each year or period.

Apportioning Depreciation

METHODS OF APPORTIONING DEPRECIATION.—Numerous methods and plans have been used to apportion or spread the total amount to be depreciated over the various accounting periods in

the estimated life of the property. The following eight methods have some standing:

1. Annuity
2. Compound Interest
3. Sinking Fund
4. Reduced Balance
5. Sum of the Years' Digits
6. Straight-Line
7. Production and Service Output
8. Machine-Hour

These methods are all discussed below. The first three methods have had only limited application in manufacturing.

ANNUITY METHOD.—The annuity method is based on the theory that interest on the investment in plant assets should be computed in arriving at income, and that allowances for depreciation, plus interest, each year, should give an equal annual charge. As this method provides for allowing interest only on the depreciation value of asset, it is evident that charge for interest each year will be less than preceding year, to the extent of interest on additional depreciation allowed in the preceding year.

The greatest objection to this method, aside from complexity involved in figuring, is that the depreciation charge becomes heavier each year and is heaviest in the last year of estimated life of the unit. From the purely practical viewpoint, a method which charges off less depreciation in the initial period than toward end of life cannot be considered safe. Also, besides being highly complex, the basic concept of introducing interest into cost is challenged. As interest is also used in methods 2 and 3, the view opposing use of interest in costing is presented here in summary.

If interest (return on capital) is to be a charge against cost and recovered in the price charged, the resulting revenue should be disbursed as dividends, after paying any interest on borrowings. Depreciation amounts recovered annually should be used to maintain and restore assets at their original capital value, or be disbursed as a distribution of capital (namely, depletion dividends of mining companies). Depreciation funds may be held in reserve over interim periods, but should then yield "other income" equally available for distribution. A fixed interest charge against equipment is not a practical theory; business aims to earn "all the traffic will bear" without encouraging competition by excess profits. When business activity is low, fixed interest in cost is a handicap in competition. Introduction of interest into cost complicates and reduces clarity of accounting and adds to clerical and management expense.

COMPOUND INTEREST METHOD.—Paton (Accountants' Handbook) explains the compound interest method and shows its distinction from the annuity method as follows:

The essential difference between the annuity and compound interest methods consists in the treatment of the hypothetical interest or income element. Under the annuity method the estimated interest on the remaining book value is each year included in the depreciation charge and credited to income. Under the compound interest plan, the interest on the remaining book value is in effect credited to the gross amount of depreciation, or, to put it somewhat more precisely, the estimated interest on the funds liberated from the asset being depreciated is added each period to

the periodic instalment which, including such interest, will accumulate to the total amount to be depreciated during the life of the asset.

SINKING FUND METHOD.—The sinking fund method consists of establishing a sinking fund by crediting thereto instalments at equal periods for equal amounts and crediting thereto interest at a given rate, with the purpose in mind of having sinking fund instalments plus interest thereon equal the amount of investment, less a residual or salvage value, if any, at the expiration of the estimated useful life of the unit.

The method is often used as a device intended to insure payment at maturity of long-term bonds issued for expansion. The modern tendency is toward issuance of serial bonds with maturities divided into annual portions. This plan allows the depreciation share of revenue to be used directly to extinguish the debt and eliminates the need for a sinking fund.

REDUCED BALANCE METHOD.—The reduced balance method consists of deducting at the end of each period a percentage of the value remaining from the previous period, sufficient to reduce the unit to its salvage or residual value at the end of its estimated useful life.

This method has an objection. Due to the application of a constant percentage, it places the heavy burden on earlier years or periods of life of the unit, and leaves an almost negligible amount to be charged off in later years. This procedure, however, is somewhat offset by the fact that, in later years, it is anticipated that upkeep and maintenance charges will be much greater than in earlier years and therefore the cost of depreciation, plus maintenance, over the periods will be more nearly equalized.

SUM OF THE YEARS' DIGITS METHOD.—This method, like the reduced balance method, provides for writing off depreciation in reduced amounts. The amount written off each year is obtained by multiplying the total depreciation by a fraction, whose numerator is the digit representing the life of the asset taken in reverse order, and whose denominator is the sum of digits representing the years of life of the asset.

Digits representing life of an asset are 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10. Their sum is 55, which is denominator of all the fractions. Numerators are 10, 9, 8, 7, 6, 5, 4, 3, 2, and 1, respectively. The tabulation below shows how they are applied in a case where the total depreciation was $7,900.

Year	Fraction		Total Depreciation		Annual Depreciation Charge
1	10/55	×	$7,900	=	$1,436.36
2	9/55	×	7,900	=	1,292.72
3	8/55	×	7,900	=	1,149.09
4	7/55	×	7,900	=	1,005.45
5	6/55	×	7,900	=	861.82
6	5/55	×	7,900	=	718.19
7	4/55	×	7,900	=	574.55
8	3/55	×	7,900	=	430.91
9	2/55	×	7,900	=	287.27
10	1/55	×	7,900	=	143.64
					$7,900.00

STRAIGHT-LINE METHOD.—The straight-line method divides the net depreciable value into equal diminuents for each year or period of expected life. If the annual depreciated values are charted, the resulting age-value curve is a straight line. The method commends itself to most accountants and executives because of its extreme simplicity. It is attacked as being inaccurate and unreliable, but accrued depreciation is only an estimate, subject even after most careful determination to many conditions that cannot be taken into consideration at the time the estimate is made.

Hence it is advisable to simplify the method of calculation as much as possible. If, during the life of the asset being depreciated, facts develop to revise the original expectancy of life, it will be necessary to adjust both existing depreciated book value and current depreciation rate chargeable to cost. Such adjustment to actualities is facilitated by the simplicity of the straight-line method.

Fig. 36 illustrates the difference of depreciation curves by the reduced balance and the straight-line methods, using 25-year life.

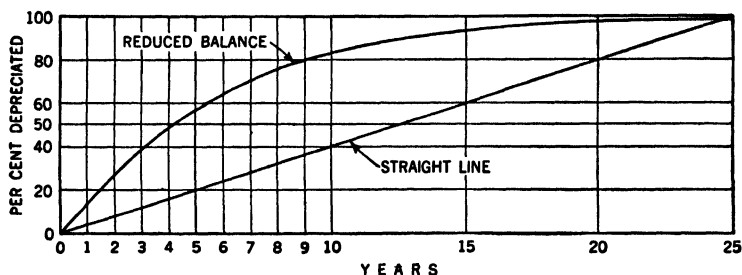



FIG. 36. Comparison of Reduced Balance and Straight-Line Depreciation

Fig. 37 illustrates an example of the adjustment of an initial life estimate of 25 years, revised at the end of the tenth year to a remaining expectancy of 5 years, or a total life of 15 years. In this case the accumulated depreciation of 49% must be augmented by write-off of 26.67%, and the annual depreciation charge increased from 4% to 6.67%.

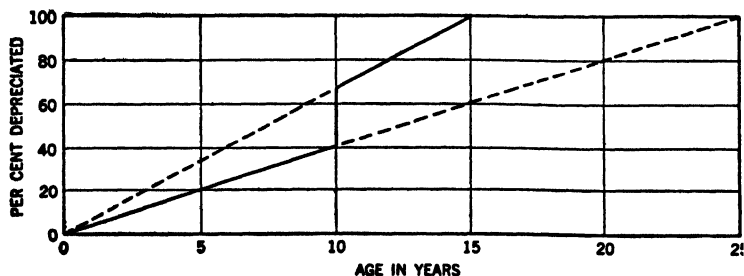



FIG. 37. Straight-Line Depreciation Adjusted for Life Expectancy

A counterclaim for the reduced balance method is that adjustments for reduced life expectancy are infrequently required because the initial write-off is rapid. The tabulation below compares the main features of these methods.

Item Considered	Straight-Line Method	Reduced Balance Method
Regular depreciation accounting	Simple percentage.	Separate table for each depreciable unit.
Addition of equipment to group	Can be merged.	Separate account must be kept for each age group.
Write-off rate suitable for	Constant low-risk, long-lived, heavy facilities.	Initial rate high machinery used in specialty and style goods manufacture.
Adjusting life expectancy	Simple calculation.	Requires new depreciation table.

PRODUCTION AND SERVICE OUTPUT METHOD.—During periods of business recession, numerous efforts are made to develop production output methods based on operation in an attempt to correlate costs and results.

The objective is usually to develop cost figures containing only utilized depreciation. Costs thus relieved of the element of unearned depreciation may encourage acceptance of marginal business to maintain the activity of the plant. The principal production bases for apportionment are:

1. Total units of product or service.
2. Total operating time.
3. Sales volume.
4. Jobs started.

The first of these bases involves an estimate as to the total number of units of product to be turned out. Such an estimate is often difficult, if not practically impossible. For this reason operating or active time is a simpler basis than physical output. Sales volume is unsatisfactory as it is often more difficult to estimate than volume of product. The job or order basis is useful where units of product are large such as buildings, ships, locomotives, and special items of equipment involving considerable expenditure.

Service output as a basis depends upon the estimate of the total service life of the item of equipment. Kester (Depreciation) has this to say concerning the method:

> Under this method the life of the asset is reckoned in terms of quantity of output. . . . Thus the life of a water filter may be expressed in terms of gallons or cubic feet of water run through it; that of a rock crusher in terms of cubic feet of rock handled; that of a freight car or locomotive in terms of car miles; and so on.

MACHINE-HOUR METHOD.—In most cases the machine-hour method will give most satisfactory results. Where a simplification of this method is desired, machines may be grouped in units or departments. In cases where depreciation is directly affected by the use to which the unit is put, it is often advisable or necessary to compute depreciation on the basis of use.

For example, take the furnace in a malleable plant, including stacks, etc. It is almost self-evident that such a furnace will last much longer

where only one heat every other day is taken, than will a furnace used to capacity and with at least two heats taken every day.

In such a case, or in the case of machinery or other assets that waste proportionately to the hours that they are actually in use, it is sometimes advisable to compute depreciation on the basis of hours used. This is done by estimating the probable number of hours or periods that the machine or unit can be used before being worn out, care being given to consider properly in the estimate various factors affecting depreciation. The total number of hours or periods having been determined, figure a rate per hour or period that will reduce the machine or unit to its estimated residual or scrap value at the expiration of such a number of hours of use. Thereafter, for each hour or period that the machine or unit is in use, an amount representing the "machine-hour rate" should be charged into costs and credited to the depreciation fund or reserve.

Because this method depreciates the property in proportion to intensity of use, it is particularly applicable to plants with wide variations of annual business volume. It accumulates depreciation reserves principally in periods of high activity when revenue is above normal and can best support the depreciation charge. It is to be noted that this method, in effect, results in depreciation charges proportionate to output, which principle is accepted for tax purposes (Treasury Department Ruling). It is proper and wise to utilize a depreciation method which augments depreciation reserves in times of stimulated activity. Such reserves permit extra maintenance and renewal work in times of subnormal activity and aid in stabilizing employment.

HOW TO SELECT METHOD OF APPORTIONMENT.—From the point of view of industrial operation, the ideal method of distributing depreciation charges would be one that would apply to each unit of product its just proportion of the total. Further, the service life of a unit of physical property should be distributed evenly over its output. These two principles apply not only to depreciation charges, but also to the accompanying expenditures for repairs, maintenance, upkeep, and the like.

A depreciation plan is not easily changed, and hence should be set up with the long-term viewpoint, considering life of property and varying conditions during this term of life. For good organization, a meeting of the minds of all concerned should be brought about. The factors to consider and the executive who is responsible in each case are:

Factor	Executive
Property life, physical	Plant engineer
Possible equipment changes	Production engineer
Demand for products	Sales and research executives
Cost accounting	Cost accountant
Taxes	Treasurer, tax accountant

SECTION 20

CLASSIFICATIONS AND SYMBOLS

CONTENTS

SECTION 20

CLASSIFICATIONS AND SYMBOLS

METHODS FOR TRANSMITTING INFORMATION.—In industrial operation the orderly, organized arrangement of facts and information is a prime essential. In satisfying this requirement an important part is taken by each of three devices: forms, classifications, and symbols. They are an integral part of the system or normal routine of operation. A form is a paper layout by means of which information is recorded and transmitted. A classification is a grouping of items having similar characteristics into classes or groups. A symbol is a contracted or shortened expression for an entity or idea. Symbols and classifications greatly facilitate convenience and use of forms.

DEFINITIONS OF TERMS.—Definitions of these aids to record-keeping, in their common industrial applications, are:

System. System is the normal routine by means of which the activities of an industrial organization are carried on and controlled.

Form. A paper form is a standardized arrangement for recording and transmitting facts. Records of transactions in industrial operation, sometimes called paper work, are made on forms.

Symbol. A symbol is a significant indication, mark, character, or group of characters (called components or designations) which may consist of figures, letters, or signs chosen to typify or represent an idea or item.

Abbreviation. A shortened or contracted form of a word or expression.

Graphical symbol. A sign used on diagrams, plans, and drawings to represent an item or object.

A familiar example is found in the symbols used on electrical wiring drawings and diagrams to indicate the various fixtures, cables, connections, and the like. Another example is found in the signs used on process charts.

Mathematical sign. A sign used to indicate a mathematical operation which is to be performed.

Mathematical symbol. A letter, character, or group of letters used in a mathematical formula or equation as representative of some number which is to have performed upon it the operation indicated by the equation.

Fundamentals of Classifications and Symbols

NATURE AND IMPORTANCE.—Classification is the beginning of the organizing of facts and information. As a process it may be applied to major groupings or to minute details; thus industry may be classified as a whole and each class then subdivided into subclasses. As an example, industry may be grouped into metal-working, textiles,

leather, rubber, and the like. The Bureau of the Census has adopted 20 such major classes. Activities of an industry may also be classified; for instance, finance, purchasing, production, sales, accounting, etc.

In fact there is almost no limit to the degree to which classification can be carried.

Classification of **the activities** of any given industry is necessary for good operation. Unless they are subdivided, it will be difficult if not impossible to establish comparisons or find costs, and thus ascertain which sections are being run at a profit and which at a loss. Unless such knowledge is available, the management has no way of properly directing business. Necessity for classification is immediately apparent in the accounting system, for it is here that costs are found and comparisons are made.

Particularly important is classification of **items of expense.** These should be subdivided to show all activities whose cost it is desired to control.

Symbols are characters or short-hand designations of ideas and concepts. They are necessary for ease and preciseness of expression and brevity in presenting recurring facts and information.

The **economy** of classifications and symbols cannot be too highly stressed. These standardized representations, groupings, and arrangements have a common purpose, namely, to save mental effort, time, and expense, and to prevent troublesome and costly mistakes. They permit concentration on the subject matter of information, reports, and orders with a minimum of attention to the way these papers are expressed. They aid in recording, transmitting, and comprehending ideas and instructions, and reduce the expense, inconvenience, and ill will of mistakes, misunderstandings, and wrong actions. They concern all aspects of industrial operation, for classifications, forms, and symbols are practically useful in every manufacturing activity.

RELATION BETWEEN CLASSIFICATIONS AND SYMBOLS.—The procedure of classification is to develop a system of classes or groups, or a systematic division, of a series of related items. Symbols develop naturally from classification of activities in industry. As each activity is classified it is designated by a letter or a number to represent the class. As each classification is subdivided, each subdivision is likewise denoted by a letter or number, and the combination of the two gives a symbol which immediately identifies the particular subdivision under consideration. This continuous breakdown eventually leads to a symbol which identifies the most minute item in the activities of a concern.

As an example, codes of symbols are imperative in production planning and production control, for in both of these activities it is necessary repeatedly to identify parts, materials, operations, small tools, machine tools, production centers, and many other items. If all these production factors are identified by symbols, time and space are saved in setting up production plans and control data, and making the numerous entries required in routine forms.

USES OF SYMBOLS.—The purpose of symbols is: (1) definitely to indicate a particular item, to the exclusion of all others; and (2) to obtain brevity in writing of orders, reports, documents, etc. It is easier

to write LE-20-CS than "cross-feed screw in carriage of 20-in. engine lathe." Symbols promote definiteness, because a symbol is associated with one thing and one only. Descriptions may be vague, even though words are used in the sense of their dictionary definitions, for the reason that all persons do not ascribe the same meaning to words.

Symbols are used to designate machines, locations, parts of products, operations, etc. In the issuance of an ordinary job ticket for a machine-shop operation, most information may be conveyed by symbols. The part upon which work is to be done will be designated by a part symbol; the department of the shop and the machine on which the operation is to be performed also will be indicated by symbols. The particular class of operation and its sequence will be symbolized. The next location or operation to which the part will be moved can be shown by a symbol, and tools to be used also will be indicated by symbols. Finally, the account to which work is to be charged will be shown by symbols on the job ticket. In fact, were it not possible to use symbols for describing activities of manufacturing, many achievements of modern management would be impossible.

Another use of symbols is in filing or storing. Symbols may be **self-indexing,** so that symbol of an article immediately locates its position in a file or a storeroom. However, it is well when considering the design of symbols for factory use, to remember that the finished product must be sold to customers. It is difficult and unsatisfactory for a buyer not constantly using such symbols, to refer to a pneumatic drill by a long string of letters or numbers. A type name serves better. "Little David" or "Slugger drill, size . .," is catchy, easy to advertise, and remains in the mind of its user.

PRINCIPLES OF SYMBOLIZATION.—Principles to be followed in planning a system of symbols and selecting the components of a symbol are:

1. A symbol should be exclusive and should completely differentiate the item it represents from every other item in the system.
2. A symbol should indicate, if possible, by its form the class and principal subclasses in which the item represented by it belongs.
3. A component or designation of a symbol should include all that follow it, and limit all that precede it.

The position of each component of a symbol has significance. The first component may represent a general class, the second the principal subclass, and the third the division of a subclass.

For instance, in a **machine-tool classification,** initial letters L, P, B, and D in symbols may be taken to represent lathes, planing, boring, and drilling machines, respectively. The second letter may be taken as representative of the type of each machine in the several classes. Thus LE would represent engine lathes; LT, turret lathes; LS, speed lathes, etc.; while PP would represent planers and PS shapers, respectively. Size might be represented by figures, or by a third letter, to which is arbitrarily assigned a value in some numeric scale. Thus LE-20 would represent a 20-in. engine lathe.

The symbol could be still further carried out to designate a particular **part of machine:** LE-20-B might represent bed, and LE-20-C carriage of a 20-in. engine lathe. The addition of still another letter to the symbol

would cause it to represent some subdivision of the part previously symbolized. Thus, LE-20-CS might be taken as symbol of cross-feed screw of carriage of a 20-in. engine lathe.

An author or developer of symbols, or groups of symbols, should realize that before they can be used, before any one can understand the ideas or subject matter to which they apply, the symbols themselves must be mastered. It is advantageous therefore to construct simple, easily understood symbols and to transmit them to user and reader in a convenient form. In a written report, paper, article, or book a complete table of symbols should be given, preferably in the opening paragraphs, so that they will attract the reader's attention, and avoid puzzling, time-consuming search for this information.

SYSTEMS OF SYMBOLIZATION.—Five systems of symbols are in practical use in industrial operation:

1. Alphabetic, in which each item symbolized is indicated arbitrarily by a letter or combination of letters.
2. Numeric, in which each item is indicated by a number or combination of numbers.
3. Mnemonic, in which the symbol for each item suggests the name it represents. It may represent by letter or combination of letters, or include numbers to designate size.
4. Sign and signal, in which each item is represented by visible or audible signs or signals.
5. Mixed systems, in which each symbol is made up of both figures and letters.

ALPHABETIC SYMBOLS.—A system of alphabetic symbols is usually simple and is applied to only a few items. It serves but little purpose except as a means of identification and an index is necessary for its use. More symbols are found in business practice than in industrial operation. Thus letter designations are common for general accounts and recurring commercial transactions. Other examples are found in the sciences, such as the use of letter symbols in mathematics.

NUMERIC SYMBOLS.—Numeric symbols may be either arbitrary assignments of numbers, without regard to relative significance of symbols adjacent to one another in the numeric sequence, or they may be built up according to a definite system, in which both the number as a whole and the various digits which comprise it have a significance. The former method has little to commend it, save that it differentiates each numbered item from every other item. To use it, an index is necessary, both when it is desired to put an item in its proper place and to withdraw it from a file or other location. The symbol serves merely as an identification, and has no assisting construction.

On the other hand, numeric symbols, derived according to some **definite system of classification**, may serve many purposes other than mere identification. They may indicate the class in which the item symbolized belongs, and may also indicate its location in a file or storeroom. A single numeric symbol may apply to several distinct entities, each related to the others in some manner, and yet the same numeric symbol will be as exclusive as if different symbols were applied to each entity.

For instance, the number of a drawing of a machine part may also be the pattern number, and in addition may represent the part number in the finished machine. There is no confusion, for the use of the symbol clearly indicates the nature of the item called for. This method has several advantages. A purchaser will order a repair part by its number from the manufacturer. This number, copied onto various working papers necessary to produce the part, will indicate to the pattern storage the correct pattern to be forwarded to the foundry, and to the drafting room and machine shop the number of the drawing needed in the shop. All this recording is accomplished without reference to a pattern or drawing index. If instructions or other papers relating to the part in question are also given the same symbol, they are located and issued with the same lack of trouble or confusion.

Building numeric symbols requires careful thought, and depends on the object sought by symbolizing. If a manufacturer has a product consisting of, say, five different lines, he may set aside five blocks of numbers for each line. Thus, all numbers from 1 to 9,999 may represent one line, from 10,000 to 19,999 another line, and so on. The first digit in the symbol then will instantly indicate the line. The second digit in the symbol may be taken as representing some major subdivision of each line, or if there are more than ten such subdivisions, the next two digits may be used as key numbers. The two final digits will designate the particular item that it is desired to classify.

Another method of building numeric symbols is to form a **series of groups,** separated by dashes. The first group has one significance, the second group another, and so on. The position and value of digits in each group may or may not have a significance, as desired. In the case of a manufacturer building a number of different machines, each type of machine may be given a number, either arbitrarily or according to some definite system of assigning numbers, as described in the preceding paragraph. Each principal subdivision of several machines may be assigned a number that will always represent that subdivision. For instance, bedplates might be represented by numbers running from 1 to 99, frames by numbers running from 200 to 299, etc. Then a combination of the two groups of numbers would identify a particular part in a definite subdivision of a certain machine. In such a system the symbol 21–317 might indicate that the part in question was piece 17 in driving mechanism of machine type 21. Similarly, symbol 107–215 might indicate a definite piece in the framework of machine 107.

The numeric system of symbols is capable of **infinite variety and extension.** Objection is sometimes offered that it is incapable of being memorized and requires an index. This, however, is true of practically every system. Even the mnemonic system, which is supposed to suggest by the form of symbols the name of the item symbolized, breaks down in this respect when the symbol contains more than three or four letters, and an index of some form is ultimately necessary.

An example of a numeric classification and symbolization of machine parts is shown by 10 **numbers of standard screws** used in the ATF 17 x 22 Kelly Automatic Printing Press.

1705 Button Head Screw, 8–32 x 3/16
1708 Button Head Screw, 8–32 x 7/32
1716 Button Head Screw, 10–32 x 3/8

1717 Button Head Screw, Special, 10–32 x 3/8
1728 Square Head Collar Screw, 1/4–24 x 3/4
1734 Square Head Collar Screw, 5/16–18 x 1 1/4
1755 Fillister Head Screw, 8–32 x 3/8
1756 Fillister Head Screw, 8–32 x 7/8
1757 Fillister Head Screw, 8–32 x 5/8
1759 Fillister Head Screw, 10–32 x 1/2

MNEMONIC SYMBOLS.—Mnemonic symbols, or symbols designed to assist the memory, consist usually of letters. The first letter of the symbol designates the general class to which the item symbolized belongs, and successive letters indicate in each case a subclass of the class indicated by the letter immediately preceding. Mnemonic symbols are especially useful, (1) for designating locations, as in storerooms, shops, etc.; (2) for designating accounts, equipment, machinery, etc., in a factory; (3) for designating products and subdivisions of product. For certain classes of product, however, the mnemonic symbol becomes somewhat clumsy when carried to its ultimate subdivision, and a numerical symbol may be substituted to advantage.

A set of rules for building a mnemonic system of symbols was given in a paper presented before the Taylor Society by Williams (Taylor Soc. Bul., vol. 2). An abstract of this follows in which these definitions are used:

One or more letters symbolizing a word or words are termed a **symbol.**
The separate letters in a symbol, and the words for which they stand, are termed **designations.**
The first designation in a symbol is termed **root designation,** as F ("Function") in symbol FCM; C ("Cost") in symbol CAD.

The **root designation** in a symbol indicates the character of the symbol. All the rest of the designations in a symbol qualify the character of the symbol.

It is sometimes the practice to divide the alphabet into three groups, omitting I, O, and Q, thus:

A to E to represent expense symbols.
G to W to represent product symbols.
X to Z to represent construction symbols.

The purpose of this plan is to distinguish clearly between the nature of the symbols used, and to prevent the confusion which might exist if several departments developed separate symbols for different uses but employed certain identical symbols. The same symbol would mean different things in different departments.

A **subindex** representing every desired qualification of each designation within these groups is then developed. Expense symbols are constructed so that they indicate the method of accounting and product symbols to form an analysis of production.

All root designations with definitions should be written on one sheet constituting the first page of a master index.

Each root designation should, in turn, be written at the head of a separate sheet, and designations (with definitions) representing first qualifications of the root, listed below. Each succeeding qualifying designation, headed by the preceding designation, should in turn be written at the head of a separate sheet, and further qualifications made in like manner.

Words beginning with I and O should be used as designations as little as possible, and when used, should be placed opposite J and K, respectively. This is because J and K are seldom used, and therefore confusion through double meaning will be infrequent. Words beginning with Q and Z may easily be omitted as designations, and therefore no provision need be made for them.

Numerals may be used as designations. They are often desirable and sometimes necessary where there are more qualifications than there are letters. Where they are of major importance, they should be put before the designation which they qualify, instead of after it as with letters. Numerals, however, may be used at the end of a symbol for definite designations of specific items, or to indicate sequence in the thing symbolized, such as order, or lot number, etc.

Qualifying Designations in Mnemonic Symbols.—Every designation should begin, as far as possible, with the letter which is to represent it in the index. To accomplish this purpose, all qualifying designations, at any given stage in the construction of a symbol, should first be written opposite the letter with which the designation begins. This method will frequently cause several designations to be placed opposite the same letter, at this preliminary stage.

To deal with the letters opposite which there are several designations, one at a time, look over designations, and select the one least used. Then consult a thesaurus (an essential in making a mnemonic index), and see if a substitute word can be found that begins with a letter which has no designation opposite it, and which for symbolic purpose will be equally descriptive.

If there still remains a letter with more than one designation opposite it, apply the letter to the least-used designation, for the reason explained in the next paragraph. Then select the designation most used, and put it opposite the second letter in designation. If this is in use, then the third, and so on down, always, however, giving preference to a letter carrying the **dominant sound** of the designation. As an example the letter "V" is dominant in the word "service."

The natural tendency is to leave the designation most used opposite the letter which characterizes the designation. The reason for doing the reverse is that it is easier to remember an inconsistency that is frequently used than one seldom used. When placing designations opposite letters other than the one characterizing it, always give preference to unused letters, so that the letters most generally applicable will be left available.

Every designation should describe rather than arbitrarily designate the thing symbolized.

Special care should be taken always to **use the same designation for the same thing** or meaning. For example, do not in one place term money paid to employees "Payroll," and in another "Wages," or "Labor." Opportunity for this type of inconsistency is limitless, and care must be exercised to avoid it.

Designations constantly recurring throughout all symbols, such as "Miscellaneous," meaning not otherwise classified, should be placed opposite letters which have the least mnemonic use. The letter X is suggested together with use of the designation "Not otherwise classified," as being more definite than "Miscellaneous."

	Flanged	Screwed	Bell and Spigot	Welded	Soldered
140 Single Sweep Tee					
141 Double Sweep Tee					
142 Reducing Elbow					
143 Tee					
144 Tee—Outlet Up					
145 Tee—Outlet Down					
146 Side Outlet Tee Outlet Up					
147 Side Outlet Tee Outlet Down					
148 Cross					
149 Reducer, Concentric					

FIG. 1. Graphic Symbols for Use on Drawings of Pipe Fittings and Valves (Developed under the procedure of the ASA, and published by Reproduced with the per-

FIG. 2. Graphic Symbols for Use on Drawings of Refrigerating Equipment.
The American Society of Mechanical Engineers, New York, N. Y.
mission of the Society.)

When the **number of qualifications** is greater than the available letters, and numerals are not desirable, the use of the designation "Various" opposite V is suggested as indicating reopening of the alphabet. The V in this case is used as a silent letter in the symbol, and the designation qualifying it should have some special characteristic. For example, in a stores symbol it is well to put all given names—that is, manufacturing names—after the designation V.

Taylor and Gilbreth adopted the use of V in the above sense. In the materials and parts classification S was used for "stores" and V for "variety." A mnemonic symbol headed by the combination SV thus represented an item of stores used for a variety of purposes. The remainder of the symbol identified the particular kind of material or part.

In a designation of two or more words, such as "Direct Purchases," the dominant or distinguishing word of the designation (Direct) is the word to be considered in determining the letter opposite which it shall be placed, as it is the one which will most naturally occur to the memory.

Signs Used in Mnemonic Symbols.—In using incomplete symbols always put an = (equals) mark to indicate a missing letter or letters. In this way a symbol without an equality sign indicates a complete symbol, whereas, on the other hand, where there is an equality sign, it not only indicates an incomplete symbol, but wherein it is incomplete. In combining symbols a right slant / can be used to indicate "or." and a left \ slant to indicate "and" if it is necessary to draw definite distinction.

In **compounding symbols** use the hyphen to indicate that the meaning of each symbol is modified by the other symbols in combination with which it is used. The hyphen is also used to express a number of symbols having a common root. Use arithmetical signs, + for plus, − for minus, × for multiply, and ÷ for divide.

These last rules are essential to the use of symbols in writing instructions, though for ordinary purposes of designation they are unnecessary. There are a number of other modifying signs which add greatly to the utility of symbols in industry, which are not given because their use is special. The tendency to use signs indicates a broader and more comprehensive use of symbols.

Typical Mnemonic Classification.—A typical mnemonic classification and **base sheet for factory accounts**, developed along the lines explained in the paragraphs above, is given by Walker:

A – Auxiliary department expenses
B – General administrative expense
C – Selling expenses
D – Shop expense
E to R – Worked materials—manufacturing products
S – Raw material stores
T to W – Worked materials—manufactured products
X Y Z – Construction—plant accounts

The following are examples of further subdivisions of the expense classification:

AHM – Repairs and renewals of machinery in the heating department
- A – Auxiliary departments, which designate those that are essential to manufacturing, but not directly concerned with production
- H – Heating department
- M – Machinery in the heating department (Repairs and renewals are charged to this account.)

BL – General administrative salaries and wages
- B – Business department
- L – From the dominant sound of the "l" in salaries

CS – Supplies; such as stationery, etc., used in the sales department
- C – From the sound of the first letter in "selling"
- S – Supplies

DBT – Repairs and renewals of tools and jigs in the bending department
- D – Shop expense (indirect or overhead expense in manufacturing)
- B – Bending department
- T – Tools and jigs used in the bending department

SIGNS AND SIGNALS.—Signs and signals, forms of graphic and audible symbolization, are in wide use in industry. These may take the form of a system of drawn devices or diagrams which, to some degree, indicate the items to which they apply, a system of colors, or a code of sounds. Examples of pictorial signs are those associated with the therbligs or elements of hand motion diagrammatic symbols for electrical machinery and apparatus, graphical symbols such as those shown in Figs. 1 and 2, and many others. The two illustrations in the above figures are selected from "American Standard Graphical Symbols for Use on Drawings" (A.S.A. Z32.2–1941). Fig. 1 represents the standard conventional manner of designating one kind of pipe fittings, Fig. 2 shows the standards adopted to indicate equipment and fittings used in refrigeration. Many more are given in the pamphlet.

An example of a **system of color symbols** recommended by the American Society of Mechanical Engineers to identify power house piping, suggests the distinctions given in Fig. 3. Additional methods for

Steam Division	a	High pressure—white
	b	Exhaust system—buff
Water Division	c	Fresh water, low pressure—blue
	d	Fresh water, high pressure boiler feed lines—blue and white
	e	Salt water piping—green
Oil Division	f	Delivery and discharge—brass or bronze yellow
Pneumatic Division	g	All pipes—gray
Gas Division	h	City lighting service—aluminum
	i	Gas engine service—black, red flanges
Fuel Oil Division	j	All piping—black
Refrigerating System	k	White and green stripes alternately on flanges and fittings, body of pipe being black
Electric Lines and Feeders	l	Black and red stripes alternately on flanges and fittings, body of pipe being black

FIG. 3. Distinguishing Colors to be Used on Valves, Flanges, and Fittings

distinction are given in "Scheme for the Identification of Piping Systems" (A.S.A. A13–1928).

A standard color system has also been adopted for all foundry patterns and core boxes of wood construction (A.S.A. American Recommended Practice B45.1–1932). It specifies that:

1. All surfaces to be left unfinished are to be painted black.
2. Surfaces to be machined are to be painted red.
3. Seats of and for loose pieces are to be marked by red stripes on a yellow background.
4. Core prints and seats for loose core prints are to be painted yellow.
5. Stop-offs are to be indicated by diagonal black strips on a yellow base.

Another application is in the flashing of codes by electric lights used in many plants to call executives to an office or telephone.

The most familiar **audible signal** is that given for starting and stopping work by the factory whistle or shop bell. In some plants gongs are controlled by a master clock to ring in every department indicating the times for starting and stopping. Still another use of audible signals is the sounding of a code on a siren or bell to call executives.

MIXED SYMBOLS.—Mixed symbols are usually made up of combinations of letters and numbers. Illustrations of this practice are found in most manufacturing concerns.

Typical Classifications and Symbols

TOOL CLASSIFICATION.—Application of classifications and symbols has been most highly developed in machine-shop practice, although their application is by no means restricted to the metal-working industries. One of the earliest classifications of this nature was the mnemonic system developed by Taylor for **metal-cutting tools.** It is reproduced in Fig. 4.

The **development of mnemonic symbols** from this general classification of small tools is illustrated by Fig. 5, 6 and 7, in which Class D—Boring, Drilling, Reaming, Tapping Tools, has been expanded into three successive subclasses, D, DD, DDT.

Numerical systems can be set up for tool classifications, with key numbers for the respective classes and subsidiary numbers for individual identification. Sometimes the designations selected for specially designed small tools, dies, fixtures, etc., are the drawing numbers assigned to such items. This latter plan, however, leaves without symbols the large number of tools of a standard kind purchased outside, and a separate or interrelated system must be developed for the latter if they are to have designations other than trade name, size, etc. When the mnemonic system is used to classify all tools, dies, and other devices, if a special drawing is made for those manufactured for specific uses, some key to the drawing numbers can be worked into the symbols, if desired.

STORES CLASSIFICATION.—There are two methods by which to classify stores in an industrial plant. One method classifies the items

A – Abrading Tools	All tools for filing, dressing, grinding, knurling, sharpening, scratching, and scraping
B – Blanking Tools	Punches and dies used for blanking, perforating and shearing
C – Holding, Leveling, and Turning Devices	Bolts, blocks, clamps, dogs, centers, jaws, jacks, knees, parallels, tool-holders, "V" blocks, milling, nut and turning arbors
D – Boring, Drilling, Reaming, Tapping Tools	All tools which remove metal from the interior by boring, drilling, reaming, and tapping
F –	
H – Chisels, Figures, Letters, and Hammers	Tools that work by striking or being struck
J – Fixtures, Jigs and Templates	For duplicating work
M – Measuring Tools	Calipers, gages, indicators, levels, squares, and scales—"tools of precision"
P – Paring or Turning Tools	Tools that remove metal from the surface by cutting, excepting milling tools
R – Milling Cutters	Angular, convex, concave, hollow and solid end mills, inserted teeth, side milling cutters, gear cutters, hobs, coarse tooth milling cutters, and slotting saws
S – Slotting Tools	Hack saws and special blades
T –	
W – Wrenches that Cause Rotation	Open end, socket, monkey, stillson, tap and reamer, extension, and Oregon wrenches
X –	
Z – Special Tools	Broaching, bending, forcing, and cutting tools

Fig. 4. General Tool Classes

Class D—Drilling and Boring Tools that Remove Metal from the Interior
Such as drills, boring bars, cutters, lathe boring tools, etc., and appliances

Subclass	Subclass
DA – Lathe boring tools	DR – Reamers, solid, adjustable bladed, etc.
DB – Boring bars	DS – Appliances for holding all tools in Class D in machines, excepting Universal and Independent clamping jaw and chucks and boring bar
DC – Cutters for boring bars, both single and double end	DT – Taps, hand and machine
DD – Drills	DU –
DE –	DV –
DF –	DW –
DG –	DX – Combination center drills DXS – With straight shank DXT – With taper shank
DH –	DY –
DJ – Countersinks	DZ –
DK – Counterbores	
DL – Tools for removing chips from holes being bored DLH – Hose attachment	
DM –	
DN –	
DP – Portable drills, operated by power or hand ratchets, "old man"	

Fig. 5. Expansion of Class D Boring, Drilling, Reaming, Tapping Tools

Subclass DD—Those Tools for Removing Metal from the Interior, Known Commercially as Drills

Subclass	Subclass
DDA -	DDN - Inserted lip drill
DDB - Drills, bottoming DDBS - Drill, bottoming, straight-shank DDBT - Drill, bottoming, taper-shank	DDP -
DDC - Drills, countersunk	DDR -
DDD -	DDS - Drills, shell DDSM - Shell drill for jarring machine DDSU - Shell drills for valves
DDE -	DDT - Twist drills (two-lipped)
DDF - Flat drills	DDU -
DDG - Gun drills DDGS - Gun drill, straight shank	DDV - Vibrator drills (two-size twist) (two-lipped)
DDH -	DDW - Vibrator drills (two-size twist) (four-lipped)
DDJ -	DDX -
DDK -	DDY -
DDL - Three (3) lip drills	DDZ -
DDM - Four-lipped drills	

FIG. 6. Expansion of Subclass DD Drills

Subclass DDT—Twist Drills (Two-Lipped)

Subclass	Subclass
DDTA - Special twist drills, two-lipped	DDTR - Straight-shank twist drill, extra length
DDTB -	DDTS - Straight-shank twist drill, standard length
DDTC - Celford twist drills	DDTT - Taper-shank twist drill, standard length
DDTD -	DDTU - Taper-shank twist drill, extra long
DDTE - Extension-shank drills, or extra long straight-shank	DDTV - Taper-shank twist drill oil tube
DDTF - Taper-shank twist drills (bottoming)	DDTW - Straight-shank twist drills, oil hole
DDTG -	DDTX -
DDTH -	DDTY -
DDTJ -	DDTZ -
DDTK -	
DDTL -	
DDTM -	
DDTN -	
DDTP -	

FIG. 7. Expansion of Subclass DDT Twist Drills

according to nature and is frequently employed. It is to be preferred where there is a wide variety of products and activities. A second method is classification according to use. This method is much simpler than the other and leads to briefer symbols.

A convenient method for setting up a stores classification is to set up a stores translation chart such as is shown in Fig. 10. The use of the data in Fig. 10 to formulate symbols, in this case mnemonic, is illustrated in Figs. 8 and 9. The symbol for any particular item is obtained by combining the symbol letters at the left of Fig. 10 with any particular letter at the top. Thus, the symbol for electric lamp sockets is SES, i.e., SE (Electrical Supplies), S (Sockets), and the symbol for brass electric lamp sockets is SESB, i.e., SES (Electric Lamp Sockets), B (Brass).

SA – Office supplies
SB – Brass and brass products including pipe and fittings
SC – Coal, coke, and other fuels
SD – Wood and wood products
SE – Electrical supplies
SF – Fastenings, bolts, nuts, nails, screws, etc.
SG – Gaskets and packing
SH – Hangers, stands, boxes, bushings, pulleys, and clutches
SJ – Gears made of all materials
SK – Chemicals and pigments
SL – Liquids, lubricants, oils, gasoline, and paints
SM – Machine and engine parts for boiler-power and water supply
SN – Metals not otherwise classified, as Babbitt, lead, zinc, etc.
SP – Pipe, pipe fittings, and tubings made from cast iron, wrought iron, and steel
SR – Rubber scrap
SS – Steel, wrought or cast iron, and products made chiefly from same
ST – Tools, implements, and supplies
SU – Building materials, such as cement, quartz, sand, and brick
SV – Abrasive, emery wheels, grindstones, etc.
SW – Wearing apparel
SX – Stores not otherwise classified
SY – Fibrous and textile materials—belts and sundries, hose, rope, and twine
SZ – Special parts and supplies for equipment

FIG. 8. Tabulating of Class S—Classified Stores
(Thompson and Lichtner)

SESA –
SESB – Brass key sockets
  SES1B – Small
  SES2B – Large
SESC – Brass keyless sockets
  SES1C – Small
  SES2C – Large
SESE –
SESF –
SESG –
SESH – Hood forks
SESJ –
SESK – Socket forks
SESL –
SESM – Mica sockets
SESN –
SESP – Porcelain key
  SES1P – Small
  SES2P – Large
SESR – Porcelain keyless
  SES1R – Small
  SES2R – Large
SESS – Porcelain pull
  SES1S – Small
  SES2S – Large
SEST – Street hood socket
SESU –
SESV –
SESW –
SESX –
SESY –
SESZ –

FIG. 9. Expansion of Subclass SES—Sockets and Forks
(Thompson and Lichtner)

COMBINATION OF STORES AND INVENTORY ACCOUNTS CLASSIFICATION.—A numeric classification of stores, used by a well-known manufacturer of household equipment, is covered in Figs. 11 to 13. The stores system is associated with the company's numerical classification of accounts, part of which, dealing with inventories of direct materials, work in process, and finished goods and parts, is briefed in Fig. 11—without the accounting instructions—to show the interconnection. Fig. 12 gives the system of stores numbers used to classify and give numerical symbols to raw materials, and Fig. 13 supplies the same information covering castings or molded parts.

To illustrate the method of application, an **example** of a number for an item of stores is given here:

51–2–53008 = Accounting designation of a certain part
51–2 = Rough purchased parts
5 = Zinc (casting or molded part)
3 = Die casting (casting or molded part)
008 = Part number designation

	A	B	C	D	E	F	G	H	J	K
SA Office supplies			Cards, ruled	Adhesives				Charts, recording		
SB Brass, bronze and pipes			Brass collars							Screen
SC Coal, coke, fuel			Coke			Fuel, soft coal		Hard coal		
SD Belts, hose, rope and twine	Absorb't cotton	Belts	Cord and rope			Felt	Beltlac'g, hooks & fasteners			Wicks
SE Electrical supplies	Tape	Batteries	Conduit and fittings		Bells and buttons	Fuses and fittings	Lamp guards	Shades and holders	Plugs	Knobs and insul'tors
SF Fastenings, bolts and screws		Bolts	Cotter pins	Wood screws		Nails and spikes	Lag screws			Cap screws
SG Gears		Bakelite pinions								
SH Hangers, pulleys and clutches		Bushings	Collars					Hangers		Brackets
SJ Gaskets, packing							Gaskets			Oakum
SK Chemicals			Carbonate of soda			Formic acid				Caustic
SL Liquids, lubricants, and paints	Shellac	Belt dressing	Cement linoleum	Paints in powder	Linseed oil		Grease			
SM Engine, boiler-power										
SN										
SP Iron pipes and fittings	Caps	Bushings	Couplings	Bends	Ells	Flanges	Tubing	Disc-holders	Sprinkler fittings	Discs and seats
SR										
SS Steel, iron	Angle iron	Bar iron	Steel channel	Galvz'd channel	Tee iron		Galvnz'd sheet		Wheels	Cables
ST Tools, implements, supplies	Taps and dies	Brushes and supplies	Containers	Drills and reamers	Screw-drivers	Files	Glass supplies	Hammers		Knives
SU Building materials		Bricks	Cement			Plaster Fiber	Gravel			
SV Abrasives			Carborundum							
SW Wood		Bungs	Chestnut		Cypress	Fiber board		Shooks		Oak
SX Otherwise unclassified			Copper flashing			Floats		Hooks		
SY Other metals		Babbitt metals								
SZ Special parts and equipment				Dry screen			Grinding mills			

FIG. 10. Stores Translation Chart

L	M	N	P	R	S	T	U	V	W	X	Y	Z
			Paper	Printed forms	Shears	Toilet supplies						
			Pipe fittings		Stock				Brass spg. wire			
				Charcoal	Black Coal							
Leather		Lining			Hose	Textile fabrics		Pipe covering	Waste and rags			
Lamps	Motors and meters			Rosettes	Sockets	Telephone material	Bolts and eyes		Wire	Supplies	Solder, wire and paste	
Expans'n sleeves	Machine screws	Nuts	Staples	Rivets	Set screws	Fasteners	Draw lugs		Washers	Tacks	Studs	Snaps
	Mitre gears	Motor pinions			Spur gears							
Clutches			Pulleys	Bearings								
			Packing									
Lime	Muriatic acid			Carbon, tetra, chloride	Salt		Sulphur					
Lubricants, oils		Turpentine	Paints in oil	Dryer	Lubricants, solid	Petroleum products	Putty	Varnish				
Pipe plugs	Stems	Nipples, nozzles	Pipe	Rail fittings	Crosses and joints	Tees	Union	Valves	Valve wheels	Cock		Faucets
	Machine steel	Screens		C R. steel	Sheets	Tool steel			Wire		Sprocket	Chain
Handles	Soaps and cleaners	Cutters	Punches	Forks	Saws			Shovels	Trenches			
					Sand		Quartz					
Oxolite												
	Maple			Hickory	Spruce				Walnut		Mahogany	
			Plaster of paris				Blue chalk					
Lead	Monel metal				Bushing stock		Aluminum					Zinc
			Pump parts	Elevator parts	Steam traps			Vises	Welding materials			

(Thompson and Lichtner)

Account 51 – Direct Materials

This account is subdivided as follows:

Account 51–1 – Raw Materials

Any material that will be changed in form or composition through machine, hand, or other processing operations, such as rolled and drawn shapes, bars, rods, sheets, tubing, wire, etc.

Account 51–2 – Rough Purchased Parts

Any part that requires machine, hand, or other processing operations, but which does not change in form or composition, such as raw castings and raw forgings.

Account 51–3 – Finished Purchased Parts

Any part that is used in its original form, such as molded parts, ball bearings, nuts, bolts, etc. For aviation contract purchases from .... Corporation, charges should be segregated into material, direct labor, and overhead elements.

Account 51–4 – Purchased Intermediate Operations

Intermediate operations purchased, such as for the .... contract from .... Corporation, should be segregated into material, direct labor, and overhead elements.

Account 51–5 – Inbound Transportation

Costs incurred for the .... Division only on productive materials incidental to their transportation from the point of original shipment to the unloading platform of the company's plant.

Each account above may be subdivided according to class of material

Account 52 – Work in Process

Account 52–1 – Work in Process—Material

This account may be subdivided as to the principal classes of products manufactured.

Account 52–2 – Work in Process—Labor

This account may be subdivided as to the principal classes of products manufactured.

Account 52–3 – Work in Process—Overhead

This account may be subdivided as to the principal classes of products manufactured.

Account 53 – Finished Goods and Parts

Account 53–1 – Finished Goods and Parts—Material

This account may be subdivided as to the principal classes of products manufactured.

Account 53–2 – Finished Goods and Parts—Labor

This account may be subdivided as to the principal classes of products manufactured.

FIG. 11. Classification of Accounts—Section on Inventories
(Manufacture of household equipment. Data condensed)

	Kind of Material		Type of Material
0	Steel	0	Sheet
1	Brass Bronze Phosphor Bronze	1	Strip
2	Copper	2	Bar-Flat
3	Aluminum	3	Round Half-round
4	Zinc	4	Hexagonal
5	Paper	5	Square
6	Cloth	6	Tubing Lap Weld, Butt Weld, Seamless } Rd., Hex., Sq.
7	Rubber Gasket Material	7	Angle
8	Insulation	8	Stamping
9	Miscellaneous	9	Miscellaneous

FIG. 12. System of Stores Numbers—Raw Material Only
(Manufacture of household equipment)

	Kind of Material		Type of Material
0	Steel Iron Malleable Iron	0	Forging
1	Brass	1	Sand Casting
2	Bronze	2	Permanent Mold Casting
3	Phosphor Bronze	3	Die Casting
4	Aluminum Palmo	4	Compression Molded
5	Zinc ZN 5 ZN 6 ZN 7	5	Injection Molded
6	Plastic Bakelite Textoil	6	Transfer Molded
7		7	Extrusion Molded
8		8	
9	Miscellaneous	9	Miscellaneous

FIG. 13. System of Stores Numbers—Castings or Molded Parts
(Manufacture of household equipment)

CLASSIFICATION OF MATERIALS AND SUPPLIES.—The numerical system of classifying and symbolizing materials and supplies used by the Detroit Edison Co. for its records and catalogs—corresponding to the items which it buys, stores, and uses—is given in Fig. 14 (A.S.A. Bul., vol. 3). The fundamentals upon which this classification is based are:

Divisions should be specific enough to exclude all duplicate listing of items or ambiguity.
Arrangement should be broad enough so that divisions will not become so numerous as to be cumbersome.

The method of classification adopted is to bring together like items wherever practicable. Following this plan, main classes are selected by a building-up process in which groups of materials which appeared allied in nature, and distinctive enough to be set apart from other items, are assembled into classes. Each class is given a name distinctive of the materials it contains, such as "Paints and Other Protective Coatings," "Bolts, Screws, Nails, Rivets," "Nonferrous Metals," "Castings," and "Pipe and Tubing." Sequence of these main classes after they had been determined upon is as follows:

Building materials and general hardware.
Mechanical equipment.
Electrical equipment.
Miscellaneous.

Within these four general groupings the classes are arranged by placing kindred materials in close proximity to one another, but the broad groupings do not appear as a distinctive part of the classification. Main classes of materials are arranged from a consideration of the degree of relationship existing between the materials grouped in each subdivision.

The **numbering system** for the items is based on a seven-digit number. The first two digits designate the main class of material in which item belongs. The third digit indicates the subclass, and the last four digits comprise a serial number. Thus an item 256–14 would be in Class 25, "Bolts, Screws, Nails, Rivets," and in subclass 6, "Rivets." It is also the 14th item in that subclass. This classification is in use by the accounting, stores, purchasing, and other departments as a basis for their various records. The numbers missing in the basic group classification are reserved for possible future additions.

CLASSIFICATION SYSTEMS FOR INFORMATION.—Printed and tabular matter in the form of magazine articles, clippings, pamphlets, reports, and similar material must be systematically filed to be available when needed. In order that this filing may be properly done a classification system must be selected. Steps involved in filing any such matter are:

1. Classify.
2. Select index symbol.
3. Compare and file index card.
4. File the article.

Librarians have devised many classifications, devices, and systems, the purpose being to secure:

1. A logical classification.
2. Simple, economical, and flexible index.
3. Provision for easy insertion of new subjects.

These requirements are difficult to satisfy for they are somewhat contradictory. However, among the systems which have had extensive acceptance, the decimal classification system is most widely used and has found the greatest favor.

Numeric Classification: Dewey Decimal System.—The decimal classification was published by Melvil Dewey in 1876 in a pamphlet providing about 1,000 classes, and including a relative index to the tables. This index he considered his important contribution.

10. Masonry and Concrete Material
11. Cut and Artificial Stone
13. Lumber
14. Poles, Cross Arms, and Other Wooden Line Material
15. Building Insulation and Lumber Substitutes
16. Paints and Other Protective Coatings
18. Glass and Glazing Material
20. Builders' Hardware
22. & 23. General Hardware
24. Line Hardware
25. Bolts, Screws, Nails, Rivets, etc.
27 Tools (Hand and Machine)
30. Iron and Steel
32. Nonferrous Metals (Aluminum, Brass, etc.)
33 Castings
35. Building Service Equipment
36 Chain, Rope, Cord, etc.
38 Hoisting Machinery and Equipment
39 Mechanical Power Transmission Equipment
41. Conveying and Trenching Machinery and Equipment
43 Stokers, Burners, and Coal Preparation Equipment
44. Boilers, Economizers, Superheaters, and Air Preheaters
45. Prime Movers (including Connected Generators)
46. Condensers, Evaporator, Heaters, and Water Purifiers
47 Pumps and Compressors
49. Air and Flue Gas Cleaning and Handling Apparatus
50. Oil Separators, Reclaimers, Coolers, etc.
51. Pipe and Tubing (including Soil Pipe)
52 Pipe Fittings
54. Valves
55. Piping Specialties and Plumbing Fixtures
56 Packing and Gaskets
58. Heat Insulation
59. Refractories (Fire Brick, Fire Clay, etc.)
60. Mechanical Control Apparatus
61. Mechanical Measuring Instruments
63. Electrical Measuring Instruments (except Electricity Meters)
64. Electricity Meters
65. Motors, Generators, and Controls
66. Transformers, Regulators, and Reactors
68. Circuit Breakers, Switches, Relays, and Jumpers
70. Fuses
71 & 72. Wire and Cable Conductors
73. Underground Conduit and Fittings
74. Wiring Supplies
76. Electric Insulation and Insulators
77. Lightning Arresters
78. Potheads
79. Street Lighting Equipment
80. Lamps
82. Communication and Signaling Equipment and Supplies
83. Batteries and Battery Equipment and Supplies
84. Appliances
85. Special Gas Plant Equipment, Material and Supplies
86. Special Railroad Equipment, Material and Supplies
87. Motor Vehicles and Equipment
88. Fuel (except Oil)
89. & 90. Petroleum and Coal Distillation Products
92. Chemicals, Drugs, and Compounds
93. Textiles
94. Medical Equipment and Supplies
95. Janitors' Equipment and Supplies
96. Office Equipment and Stationery Supplies
97. Restaurant Equipment and Supplies
93. & 99. Items Not Otherwise Classified

---

16 Paints and Other Protective Coatings
- 16-0 Prepared paints
- 16-1 Paint ingredients
- 16-2 Bronzing material
- 16-3 Driers
- 16-4 Fillers
- 16-5 Thinners
- 16-6 Shellac and varnish
- 16-7 Lacquer and enamel
- 16-8 Other protective coatings
- 16-9 Miscellaneous protective coatings

25. Bolts, Screws, Nails, Rivets, etc.
- 25-0 Anchors, shields, etc
- 25-1 Bolts
- 25-2 Nuts
- 25-3 Cotters, washers, etc.
- 25-4 Brads, nails, spikes, etc.
- 25-5 Screws, screw eyes, and screw hooks
- 25-6 Rivets
- 25-9 Miscellaneous fasteners

33. Castings
- 33-0 Aluminum Castings
- 33-1 Brass castings
- 33-2 Bronze castings
- 33-3 Copper castings
- 33-4 Iron castings
- 33-5 Steel castings
- 33-9 Miscellaneous castings

51. Pipe and Tubing (including Soil Pipe)
- 51-0 Steel pipe and tubing
- 51-1 Wrought iron pipe
- 51-2 Cast iron pipe
- 51-3 Copper pipe and tubing
- 51-4 Brass pipe and tubing
- 51-5 Lead pipe
- 51-6 Aluminum pipe and tubing
- 51-9 Miscellaneous pipe

FIG. 14. Portions of a Numeric Classification of Materials and Supplie

The Dewey Classification divides the field into ten main classes, represented in the notation by the decimal system of Arabic numerals. Human knowledge is divided into nine classes, each being given a decimal number as .1, .2, .3, etc., and the numbers beginning with .0 are reserved for encyclopedias, newspapers, and other material too general in inclusion to be assigned to a specific class. Each main class can, therefore, be represented by a single numeral. Subdivision is always accomplished by tens, so that—all numbers being decimals—these subdivisions can be marked by adding an additional numeral to some existing number.

In application this system subdivides as shown by these simple illustrations:

.6	Applied science
.65	Business
.658	Industrial management
.6582	Plant, building, and layout
.65828	Service equipment. Labor-saving devices
.658281	Transportation. Conveyor systems. Handling materials. Trucks
.6582811	Hand-conveyors and hoists

.6	Applied science
.65	Business
.658	Industrial management
.6585	Shop management. Production
.65854	Rate setting
.658542	Operation studies
.6585421	Time study

In practice it is customary to omit the decimal point when writing the numbers. It is also customary to divide long numbers or symbols into groups of three figures by inserting periods beginning at the left. These groups have no significance, but make reading easier: 658.28, 658.542.1. Matter may be arranged according to **point of view,** so that theory, tests, costs, and other similar topics group together.

The **relation sign** (:) is the most important of these arbitrary symbols. When used to join two numbers it indicates that the subjects represented by them are considered in relation to each other. For example, the number for the woodworking industries is 674, and the number for management 658. Combining these with the colon, or relation sign, gives 674:658 representing the management of woodworking industries.

In 1920 the **Dewey decimal classification as extended and modified** by the Institut International de Bibliographie (this modification is commonly known as the Brussels extension) was adopted by the Engineering Societies Library. In 1921 Dewey designated to the Library number 658 as the one to be expanded into a classification of management subjects.

In 1922 the following societies—American Institute of Accountants, American Society of Mechanical Engineers, the American Management Association, National Association of Cost Accountants, and the present Society for the Advancement of Management—set up a joint committee to assist in this expansion. The Research Committee of the Detroit Chapter of the Society of Industrial Engineers also worked out an expansion. These various efforts were harmonized and combined early

in 1924 into a classification of management subjects, including production engineering, which can be used as the basis to classify books, pamphlets, and clipped material for filing.

Fig. 15 is a partial expansion of this index class 658, Industrial Management.

Number	Subject
658.	Industrial management
.11	Promotion
.14	Finance. Financial control Budget making
.16	Organization
658.2	Plant
.21	Location site
.22	Material
.23	Design
.24	Lighting
.25	Heating and ventilating
.26	Power
.27	Production equipment
.28	Service equipment. Labor-saving devices. Safety equipment
658.3	Industrial economics. Personnel
.31	Relations of capital to labor
.32	Remuneration of work
.33	Labor of children
.34	Labor of women
.38	Laboring classes
658.5	Shop management. Production
.51	Planning
.53	Time records. Production charts
.54	Rate setting
.56	Shop organization
.57	Research and experiment
.58	Shop maintenance

FIG. 15. Partial Expansion of Industrial Management (Dewey Decimal Index Class 658)

Form divisions—invented by the Institut International de Bibliographie, and usable in connection with numerical classifications—are arbitrary symbols used in a fixed arbitrary sequence. Their use permits arranging a subject historically, geographically, by commercial statistics, by countries, industries, products, etc.

The **form numbers** in Fig. 16 may be added to any number. An example of the combination of these form numbers with the Dewey Decimal Classification is the following: Engineering Standards—62(003).

Number	Form
(001)	Statistics
(002)	Quantities and costs
(003)	Contracts: Specifications. Standardization
(004)	Designs. Drawings
(005)	
(006)	
(007)	Laws and regulations
(008)	Patents
(009)	Reports (official)
(01)	Theory: Efficiency
(016)	Bibliography
(02)	Handbooks. Forms
(03)	Dictionaries
(04)	Essays
(05)	Periodicals
(*058)	Directories. Yearbooks
(06)	Societies. Congress. Conventions
(07)	Education. Teaching
(*072)	Research
(*083)	Tables and calculations
(09)	History

* Numbers marked with star are taken from Brussels expansion of Dewey.

FIG. 16. Form Numbers used in connection with Numerical Classifications

CATALOG CLASSIFICATION.—There are several ways to classify and file catalogs and circulars. These methods are:

1. Chronologically, by dates of receipt and corresponding serial numbers.
2. According to size groups, designated by key letters or numbers for the groups, followed by serial numbers within each group.

3. Alphabetic—setting up groups according to subject-nature of catalogs and assigning a letter to each group, with subletters for subdivisions of each group and further letters for individual catalogs within the group.
4. Numeric—same as alphabetic except that numbers are used for the main groups and subdivisions, followed by a dash and appended serial numbers for the individual catalogs and pamphlets. A plan similar to the Dewey decimal system also may be used, with letters at the end to differentiate catalogs where several of the latter are on the same subject.
5. Mnemonic—alphabetic designations of the major subjects, broken down in a succession of steps, with the letter symbols by their sound suggesting the subjects and subdivisions.
6. Mixed plan using two or more of the above systems together.
7. Following some existing classification or classifications, such as stores and materials, or the Federal Bureau of Specifications classification.
8. Separating circulars from catalogs and filing each according to one of the above plans.

Catalogs and circulars may be kept on bookshelves, or in regular filing cabinets with guide cards to separate the classes and subclasses. Where the catalogs and circulars are filed together, the problem of classification and filing is complicated by:

1. Difficulty of handling and storing if there is intermixing of single sheets, pamphlets, and paper-bound and stiff-covered catalogs and data books.
2. Difference in sheet or page size—varying from 3" x 5" cards (or even smaller) to 9" x 12" books or magazine pages, and sometimes larger folded sheets.
3. Variations in thickness—single sheets, and thin pamphlets up to volumes two or more inches thick.

Approximate Size	Classification for Catalogs and Circulars Together	Classifications with Catalogs and Circulars Separate			
		Plan A		Plan B	
		Books	Circulars	Books	Circulars
3 x 5	A	A	R	Ab	As
4 x 6	B	B	S	Bb	Bs
5 x 8	C	C	T	Cb	Cs
6 x 9	D	D	U	Db	Ds
7 x 10	E	E	V	Eb	Es
8½ x 11	F	F	W	Fb	Fs
9 x 12	G	G	X	Gb	Gs
Larger	H	H	Y	Hb	Hs
Odd sizes	J	J	Z	Jb	Js

FIG. 17. Methods for Classifying Catalogs and Circulars

In addition, the reserve space for expansion requires attention. With a mere chronological or size system a minimum reserve space is needed, but other systems—to avoid frequent movings—need extra space in each class.

Reference to other kinds of classifications in this Section will indicate how to develop and apply symbols for catalogs, except in the case of separation by size groups, and the separation of circulars from catalogs. In Fig. 17 are given systems for both a size classification and one which

includes also a separation of catalogs and circulars. Subsymbol "b" has been used for bound books, and "s" for sheets or circulars to prevent confusion with catalogs which would arise if subsymbol "c" were used. Fewer size groups than are shown in Fig. 17 can be used if desired. The symbol Db129 would show that the item was a 6" x 9" bound catalog, the 129th in sequence of addition to this size group.

Since old catalogs and circulars, filed under any system, should be thrown away or replaced by new ones, the year might be added to the symbol to show whether the catalog is recent and to call attention to the need for getting a new copy, if the one on file is out of date. Thus, in the above example, Db129–44 would indicate a 1944 catalog, probably useless in 1950. Replaced or old catalogs should be destroyed, or, if valuable because of data or application to something still in the plant, should be filed and indexed separately, say, with a D (discard or "dead") after the symbol, thus, Db14–38D.

DRAWING CLASSIFICATION.—The vital importance of drawings for manufacturing purposes is self-evident. Existing drawings not only are valuable and indispensable records of products already designed but also are frequently used for new work, where previously designed parts, subassemblies, etc., can be utilized. In addition to an elaborate drawing index and cross-reference file, a well-designed method of classification and symbolization for drawings is necessary for the identification and storage of the tracings, layouts, and filed blueprints. The plant engineering department also needs a suitable classification for drawings of buildings, departmental layouts, pipe lines, yard layouts, and other factors of the physical plant.

A classification may be developed according to the respective nature of the items covered by the drawings—regular products, special products designed for customers, job estimates requiring preliminary drawings and layouts, machinery and equipment designed for the plant, plant engineering layouts, or drawings of other kinds. Such a classification may be alphabetic, numeric, mnemonic, or any combination of these systems. The symbols entered should be assigned, or at least checked, by someone familiar with the system and able to make up the proper designations.

A breakdown of drawings by products for a company manufacturing a number of different lines might be developed along the following plan, which is a combination of alphabetic, mnemonic, and numeric systems:

B – Specific class of product
BA – Specific group of the class
BAA – Specific subdivision of the group
BAAA – Final assembly drawing of the specific product
BAAS – Subassembly drawing of a portion of the product
BAAP – Drawing of any part for the product
BAAPB – Drawing of a bearing
BAAPG – Drawing of a gear
BAAPG35 – Drawing of a gear No. 35 which goes on the product

The letter Y (in place of B, above) may be reserved as a key letter for drawings of machinery and equipment, and Z for plant engineering drawings. Other letters toward the end of the alphabet may be assigned for any additional special purposes. Numbers can be substituted at any point for letters where they will simplify the symbols or facilitate the indication as to the nature of the drawing.

Such a plan may be too complicated for companies making simpler or more limited lines of product. In such cases—since even under a product classification drawings would be made in **standard sizes**—it may be more convenient to assign letters to the various sizes of drawings, and file and index them according to such a system. The drawings of different products would be mixed and an index would have to be consulted to assemble the complete set for any product. This method, however, is economical of space and involves no questions of allocating identifying designations to specific products.

The classification of sizes given in Fig. 18 can be built backwards from the end of the alphabet, or forwards from the beginning—starting with the smallest size drawing—whichever way provides the most serviceable designations. Building from the back, with Z for the smallest size drawing, often is preferable. Under this plan, by Method 1, a drawing E–257 would be found in the 36" x 48" cabinet or drawer filed in numerical sequence as No. 257.

Over-all Size of Drawing Sheet (inches)	Classification Designation	
	Method 1	Method 2
9 x 12	A	Z
12 x 18	B	Y
18 x 24	C	X
24 x 36	D	W
36 x 48	E	V
48 x 60	F	T
Larger	G	S
Special	H	R

FIG. 18. Classification of Drawings by Size

PATTERN CLASSIFICATION.—A classification for foundry patterns can be developed along the same lines as one for drawings, with proper modifications. Where symbols have been adopted for parts, the patterns for the parts made from castings can bear these parts symbols, according to kinds of product or other basis chosen. If it is found more convenient to key the patterns in with drawings, the pattern numbers may correspond to the drawing numbers or symbols, especially where there are separate drawings for each cast part. When several parts are on the same drawing, they can be numbered in series and then the drawing number or symbol, followed by a dash and the part number on the drawing, will form the pattern number.

The metal, plastic, or wood patterns used as templates for marking off and cutting out leather for shoes, cloth for garments, automobile upholstery, sheet-metal parts not stamped out on punch presses, and similar purposes, can conveniently be identified by stamping, etching, or painting part or drawing numbers on them.

Separate pattern symbol systems are also practical, corresponding to a particular organized classification of their own—such as A, patterns for aluminum products; B for brass products; C for cast-iron products, etc., followed by other letters, or numbers (sometimes serially), or both. If any of the above plans are inconvenient, patterns may be classified

solely on a size basis without regard to product, material, or other special identification. This plan is particularly advantageous where patterns vary greatly in size, or are of a miscellaneous nature and are subject to alterations—such as stripping up—for various purposes, with no record existing as to the shape in which the pattern was stored after its last use, and sometimes no drawing in existence.

A system of the latter kind can be built up in the same manner as one for classifying drawings by size, the number of classes being determined by the number of convenient size-groups into which the patterns may be separated. Usually over-all maximum dimensions in length, width, and thickness or height can be set as limits, according to convenient sizes for pattern shelves, racks or hangers, or available floor space for pattern storage. Such a classification method, with assumed sizes, is indicated in Fig. 19. The number of size-groups can be held down to three or four, if more convenient.

Under this plan, the only reserve storage space necessary for expansion is that allotted for the various size-groups, even this amount being held down by the opportunity to continue in a new location a size series which has used up its allotment in the original place. Core-boxes—unless standard for a variety of patterns—and loose pattern parts should be marked with the same symbols as the patterns and stored with them. They may have subnumbers or letters to mark them as part of a main pattern.

Pattern Size—Main Pattern [1] Approx. Over-all Dimension Limits [2]			Probable Place of Storing	Classification	
Length (inches)	Width (inches)	Height (inches)		Method 1	Method 2
12	6	6	Shelf	A	Z
18	12	6	Shelf	B	Y
24	18	8	Shelf	C	X
30	18	8	Shelf	D	W
36	24	12	Rack	E	V
48	24	12	Rack	F	U
48	30	15	Rack	G	T
60	30	15	Floor	H	S
60	36	18	Floor	K	R
60	48	24	Floor	L	P
72	..	..	Floor	M	N
100 or above	..	..	Floor	N	M

[1] Exclusive of removable parts of pattern.
[2] If pattern is much in excess of any of the three dimensions, particularly the longest (length), place it in the next higher class.

Fig. 19. Size Classification for Patterns

Gated patterns on matchboards preferably should have a separate series of symbols, especially if they are to be stored apart from single patterns. However, they can bear the same base symbols as single patterns of identical kind, with a subsymbol G at the end to indicate that they are gated. This plan, however, gives rise to possible confusion where there are gated patterns of which there are no single patterns. It is necessary to make sure that the gated patterns are not given the same basic symbols as totally different single patterns—except for the G. With a separate gated-pattern system this confusion will not arise.

Under this latter plan, the single-pattern number, if needed, can also go on the gated-pattern board as a cross-reference, and vice versa.

COMBINED DRAWING AND GROUP NUMBER CLASSIFICATION SYSTEM.—In the Brewster Aeronautical Corporation there is in operation a combined Drawing and Group Number System prepared as a part of the Engineering Manual, and so set up that it can be used for a number of purposes. It provides the basis for the titling and numbering of all drawings. Filing under this number system has the advantage of bringing all drawings of a group together. The code digits of each number are the basis of weight estimating and recording, and can also be used for cost accounting, estimating, factory planning, and scheduling. All interdepartmental work is easily coordinated by this system.

The two charts in Figs. 20 and 21 show the breakdown of this number system. Fig. 20 contains only the **names and numbers** of each group and subgroup. Fig. 21 shows the **detail subjects** which belong under each subgroup and is used in determining under which subgroup each item is to be numbered.

Two-Part Drawing Numbers.—Each drawing number consists of two parts separated by a dash. The first part is the model number and the second part the code number.

Each individual model of airplane called for by a customer contract has first a **model number,** which is assigned by the chief engineer. All drawings made directly for this model use this model number as the first part of the drawing number. For purposes of illustration, Model Number 25 is used in this discussion.

The second part of each drawing number consists of a six **digit code number.** The first three digits use the code number of the group or subgroup from the chart to designate the location of the part or assembly. The last three digits are the individual designation of the drawing in the subgroup and run from 001 to 999. In some cases blocks of a hundred or more numbers are reserved for the major breakdown of a subgroup and are so indicated on the code number chart. No code numbers ending in three zeros are used on drawings. Such numbers are employed only for code purposes in charts, collecting weights, cost, etc., by groups.

A **sample detail drawing number** together with the indication of the manner in which the location of a part is indicated by the coding is shown below.

Example: 25–727211 Idler-Aileron Control

25– is the model number for the 25th Model airplane.
–727211 is the code number for the part.
The first digit 7 indicates Fixed Equipment Group.
The second digit 2 indicates Surface Controls subgroup.
The third digit 7 indicates Main Control system of Surface Controls
The fourth digit 2 indicates an Aileron item of main controls.
The last two digits 11 indicate the individual drawing number.

The **complete airplane** is brought together on the general erection drawing whose bill of material shows the main group assemblies or installations.

Example: 25–000001 General Erection Model 25 Airplane

Group / Unit	Number
GENERAL ERECTION	000001
GENERAL ARRANGEMENTS	000002
INBOARD PROFILE	000003
MOCK-UP	010000
WIND TUNNEL MODEL	020000
TEST	030000
WING ERECTION	100000
Center Section	110000
Intermediate Panel	120000
Outer Panel	130000
Tips	140000
Ailerons	150000
Inboard	151000
Outboard	152000
Flaps	160000
Landing (lower)	161000
Center Section	161100
Inner	161400
Outer	161700
Diving (upper)	162000
Center Section	162100
Inner	162400
Outer	162700
Slats	170000
Provisions for Equipment	180000
TAIL ERECTION	200000
Stabilizer	210000
Elevator	220000
Fin	230000
Rudder	240000
Provisions for Equipment	250000
BODY GROUP	300000
Fuselage	310000
Frame Structure	311000
Monocoque Section	313000
Cockpit Enclosures	316000
Noseover Structure	317000
Cowling and Supports	318000
Provisions for Equipment	319000
Booms	320000
Hull	330000
Monocoque	331000
Enclosures	335000
Provisions for Equipment	337000
ALIGHTING GEAR (LAND)	400000
Main Landing Gear	410000
Main Structure Assembly	411000
Retracting Mechanism	413000
Brake Operating Mechanism	415000
Emergency Extension Unit	417000
Auxiliary Landing Gear	420000
Main Structure Assembly	421000
Steering Mechanism	423000
Retracting Mechanism	425000
Brake Operating Mechanism	427000
ALIGHTING GEAR (LAND) (*Cont'd*)	
Emergency Extension Unit	429000
Bumper	430000
Main Structure Assembly	431000
Retracting Mechanism	433000
Brake Operating	435000
Emergency Extension Unit	437000
ALIGHTING GEAR (WATER)	450000
Main Floats Installation	451000
Main Float Assembly	451100
Float Struts	451800
Steering Mechanism	451900
Auxiliary Floats	452000
Auxiliary Float Assembly	452100
Auxiliary Float Struts	452600
Retracting Mechanism	452800
Emergency Extension Unit	452900
ENGINE SECTION OR NACELLE GROUP	500000
Engine Mount	510000
Firewall (if removable)	520000
Monocoque Nacelle Structure	530000
Tabular Nacelle Structure	540000
Engine Cowling	550000
Provisions for Equipment	560000
POWER PLANT	600000
Engine	610000
Reduction Gear Box	611000
Extension Drive Shaft	613000
Engine (less extension, etc.)	615000
Engine Accessories	620000
Supercharging System	621000
Exhaust System	622000
Accessory Gear Box	623000
Vacuum System	624000
Air Intake System	625000
Power Plant Controls	630000
Propeller	640000
Starting System	650000
Cooling System	660000
Lubricating System	670000
Oil Coolers and Accessories	671000
Oil Dilution System	672000
Oil Tanks	673000
Oil Piping	674000
Fuel System	680000
Tanks	681000
Piping	682000

Fixed Equipment, Special Equipment, and Useful Load Group not reproduced here.

FIG. 20. Drawing and Group Number Chart for Airplane Groups and Units

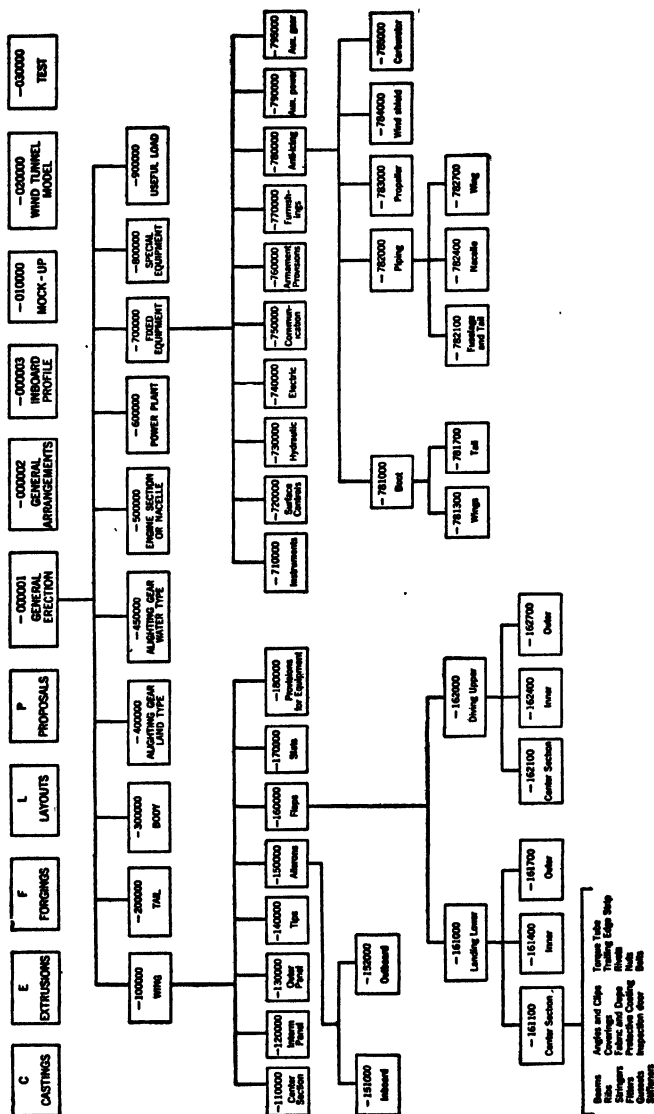



FIG. 21. Detailed Breakdown of Airplane Group Classification

The code number of **principal assembly or installation drawings** of each group will always be the three digits of the group code designation followed by a number in the 001 series. For cloth-covered surfaces, 001 is used for "Covered Assembly" and 002 for "Skeleton Assembly." For all **structural groups** the first 10 numbers are reserved for major units such as spars, beams, leading-edge assemblies, main landing-gear struts, etc. Enough consecutive numbers are allotted after the first 10 to allow for all "frames," "ribs," etc., to be numbered together. For all **non-structural groups** the first 10 numbers are reserved for the most important assemblies or installations.

Examples: 25–200001 Tail Erection
25–220001 Elevator Covered Assembly
25–220002 Elevator Skeleton Assembly
25–220003 Spar Assembly—Elevator
25–700001 Fixed Equipment Installation

Provisions for Equipment.—In each of the **main structural groups**, a code number is set aside for **Provisions for Equipment.** This code number is intended to cover permanently built-in provisions and not the easily removable items which should be numbered in their respective subgroups. The drawing number of the item is tied into the group for which it is a provision, by using as the third and fourth digits the first two digits of that group. Illustration: a clip permanently built onto the wing spar to support a removable aileron control-rod idler would be numbered in the Wing "Provisions for Equipment" subgroup. However, the idler would be numbered in the Surface Controls subgroup, e.g., 25-727211 Idler—Surface Controls—Aileron Control-Rod (Removable).

Example: 25-187202 Clip—Wing—Control-Rod Idler Support (permanently attached to wing spar to support a removable Aileron Control-Rod Idler)

The first two digits at right of dash (18) indicate a Provision for Equipment built into a wing panel.

The third and fourth digits (72) indicate that a Surface Control item is supported by this part.

In the **power plant group** the piping diagram code number ends in 001 if a single drawing and in 002, 003, etc., if more than one diagram is required.

Example: 25–674001 Oil Piping Diagram—Power Plant

In the **electrical system** the conduit diagram is considered as the master drawing with the code number –740001 and the wiring diagram is –740002. The next eight numbers are reserved for main distribution panel, switch boxes, etc.

Examples: 25–740001 Conduit Diagram—Electrical
25–740002 Wiring Diagram—Electrical

Assembly Groups.—If for assembly purposes it is considered desirable to show parts from one subgroup installed on a part of another, the drawing is numbered in the controlling group. An illustration is an assembly of instruments on an instrument board, which carries a fixed

equipment group number but with the parts all numbered in their subgroups.

Examples: 25–700002 Instruments and Instrument Board Assembly-Fixed Equipment—Pilot's
25–710003 Special Instrument—Pilot's
25–771402 Board Assembly-Furnishings—Pilot's

The **General Arrangement** -000002 and **Inboard Profile** -000003 are set off to one side on the charts because of their nature as reference drawings. While much information is given on them, they are not part of the production build-up and contain no regular bill of material.

Proposal, Layout, Parts, Model, and Test Drawings.—Proposal drawings have the initial letter "P" inserted between the model number in place of the dash. They are numbered consecutively from 1 for each subgroup. Thus, 25P210001 is the Proposal drawing of the Stabilizer for Model 25 airplane.

Layout drawings have the initial letter "L" inserted between the model number and the code number in place of the dash. Thus, 25L210001 is the Layout for the Stabilizer for Model 25 airplane.

Forgings and casting drawings have the initial "F" or "C" inserted between the model and code number in place of the dash. The number is the same as is used for the finished part except for the letter "F" or "C" and that number is reserved at the time the forging or casting number is taken out.

Example: 25F411010 is the forging for the part number 25–411010

Wind tunnel model drawings have the model number followed by a dash and the code number with 020 as the first three digits, and the last 3 digits numbered consecutively.

Examples: 25–020001 is the first detail drawing of the Wind Tunnel Model for the Model 25 airplane
25–020002 is the second detail drawing of the Wind Tunnel Model

Mock-up and test drawing numbers are coded by using -01 or -03 as the first two digits, the first two code digits of the subgroup as the third and fourth digits, and then consecutive numbers from 01 to 99 for the fifth and sixth digits as the individual designation of each drawing. This plan allows 99 numbers for each major subgroup which will be sufficient for either mock-up or test purposes. Thus, 25–012301 is a Fin Assembly drawing for the Mock-Up on Model 25 airplane.

Symbols for Production Planning and Control

TYPICAL METHODS.—Symbols adopted for purposes of production planning and control differ widely among manufacturing concerns because of differences in products, materials used, operations and processes performed, and equipment utilized. The simplest form of subsymbols is the abbreviation. Figs. 22 to 27 show how such abbreviations can be selected. The tables deal with part names, materials, operations, and machines found in machine shops or machinery building concerns. None is complete; rather, each is intended to show how typical symbols of this kind can be easily constructed.

MACHINE PARTS.—Fig. 22 lists common machine parts or assembled units, giving for each part name a simple symbol in the form of an easily recognized and remembered alphabetic symbol.

Part Name	Symbol	Part Name	Symbol
Adjusting Nut	Adj. Nut	Generator	Gen.
Anchor Plate	Anch. Pl.	Hanger	Hgr.
Arbor	Arb.	Housing	Hsg.
Armature	Arma.	Interlock	Int/L
Back Shaft	Bk. Sh.	Journal	Jrnl.
Base	Bs.	Key	K.
Bearing	Brg.	Lever	Lvr.
Blanket	Blkt.	Link	Lk.
Boss	Bos.	Lubrication System	Lub. Sys.
Box	Bx.	Manifold	Manif.
Bucket	Bkt.	Meter	Met.
Bushing	Bush.	Motor	Mot.
Butterfly Valve	Btfly. Val.	Nozzle	Noz.
Carrier	Car.	Oil Rings	O. Rgs.
Cleat	Clt.	Oil Tank	O. Tk.
Collar	Clr.	Panel	Pnl.
Connecting Rod	Con. Rd.	Piston	Pst.
Cotter Pin	Cott.	Rheostat	Rheo.
Cylinder	Cyl.	Screen	Scrn.
Dowel Pin	Dwl. Pin	Screw	Scr.
Driver	Drvr.	Shaft	Sft.
Eyebolt	E/B	Spring	Spg.
Flange	Flg.	Switch	Sw.
Foundation	Found.	Terminal	Term.
Frame	Fr.	Turbine	Tb.
Gasket	Gskt.	Wheel	Wh.

Fig. 22. Machine Parts Names and Alphabetic Symbols

A well-planned system of symbols for manufactured equipment is that developed by American Type Founders for the printing presses which it produces, as illustrated in Figs. 23, 24 and 25. The system takes into account final assembly, assemblies (intermediate), subassemblies, and parts.

The engineering department, when developing a press, makes up a complete bill of materials covering all the parts. The parts used in the various assemblies are grouped under the assemblies, parts going into final assemblies being listed separately. Letter symbols such as AG, DC, DE, etc., preceded by a number from 500 up, are assigned to these assembly groups and parts for each press. The separate parts in the assembly are numbered and, wherever possible, the number of the major part in the assembly is added to the basic assembly number. Thus, an assembly in which the major part is numbered 90 DC 330 would be designated 590 DC 330. An assembly in which the major part is 118 DC 34 would be numbered 618 DC 34. Single parts used to connect assemblies are numbered from 1,000 to 49,999. Numbers from 50,000 up also designate assemblies.

Included in the assemblies are subassemblies, so designated because they are used with single parts to form asemblies. When a new part is added to an assembly, a new number is added to it in that group. Old numbers of discarded parts are not reused.

Typical examples of the assignment of symbols are given in the accompanying figures. In the assembly 569 DC 5 (Fig. 23) the plate or blanket cylinder bearer 69 DC 5 is the major part. Adding 500 to the initial number of the part gives the above assembly number. In another assembly, 638 DC 10, shown in part in Fig. 24, the above 569 DC 5 assembly is included. However, since the plate or blanket cylinder bearers, 69 DC 5, are included with the blanket cylinder in an assembly, the 638 DC 10 number is built up on the basis of this latter major combination (labeled 138 DC 10 under 569 DC 5) by adding 500 to get the 638 DC 10 designation.

Single parts numbers such as the following are used:

2382 Rd. hd. screw
2494 Hex. hd. screw
42000 Oil can
42001 Screw driver 7/32 x 8
42007 End wrench 7/16 x 1/2
42008 End wrench 1/2 x 9/16
49864 Double tubing clip

On a previous page in this Section the numerical method of classifying standard screws in the American Type Founders is illustrated.

In Fig. 25 assembly 999 DC 82 is illustrated showing that part 499 DC 82 is the basic element (with 500 added) to give the above assembly number. The use of numerical symbols for separate parts is shown also in this illustration.

The symbols in the above system are used not only for manufacturing purposes but also in parts catalogs supplied to customers for the ordering of repair parts for presses. These catalogs contain illustrations of individual parts, subassemblies, etc., coded with symbols, for ready identification of the repair parts needed.

Assem. No.	Part No.	Description	Qty. Used
569 DC 5		BLANKET CYLINDER & BEARERS - 1st ASSEMBLY (SEE 638 DC 10)	1
	138 DC 10	Blnk. cyl. - includes bearers	1
	69 DC 5	Plate or blnk. cyl. bearer - sold only with 138 DC 10	2
	45 DC 11	Expansion plug cyl. 1 3/8 dia. - .083 thick	5
569 DC 6		PLATE CYLINDER & BEARERS - 1st ASSEMBLY (SEE 638 DC 8)	1
	138 DC 8	Plate cyl. - includes bearers	1
	69 DC 5	Plate or blnk. cyl. bearer - sold only with 138 DC 8	2
	45 DC 11	Expansion plug cyl. 1 3/8 dia. - .083 thick	5
	1491	Plug 1/2 x 3/8	3
571 DC 160		PLATE CYL. BEARING - OPER. & DRIVE SIDES	2
	71 DC 160	Plate cyl. bearing - cast iron	1
	71 DC 169	Bronze bearing	1
571 DC 161		BLANKET CYLINDER BEARING - OPER. SIDE	1
	71 DC 161	Blnk. cyl. ecc. bearing, cast iron - oper. side	1
	71 DC 169	Bronze bearing	1

FIG. 23. Portion of an Assembly Parts Classification List for Machine Parts

Assem. No.	Part No.	Description	Qty. Used
638 DC 10		BLANKET CYLINDER - FINAL	1
	569 DC 5	Blanket cyl. & bearers	1
	997	Woodruff key 1/2 x 2 1/4	1
	1777	Fill. hd. screw 1/4 - 24 x 3/4	1
	4550	Washer 17/64 x .020	1
	404 DC 235	Blnk. cyl. ratchet pawl stud	1
	1113	Cotter pin 3/32 x 3/4	1
	1346	Stop pin 3/16 x 1	1
	330 DC 22	Blanket cyl. ratchet pawl	1
	110 DC 31	Blnk. cyl. cap	1
	1960	Hex. hd. screw 3/8 - 16 x 1 1/4	2
		(Etc.)	

FIG. 24. Development of Assembly Number from a Major Part Number in Fig. 23

Assem. No.	Part No.	Description	Qty. Used
999 DC 82		SPRING ROD POPPET	1
	499 DC 82	Trip fork spring rod poppet	1
	870 DC 122	Trip fork spring rod - blnk. cyl.	1
	1113	Cotter pin 3/32 x 3/4	1
	4679	Washer 5/16 x 5/8 x 1/32	1
	301	Collar 3/8 x 7/8 x 1/2	2
	2266	Socket set screw 1/4 - 24 x 1/4	2
	28 DC 55	Poppet spring - 6 3/8" long - 1/2" O.D.	1

FIG. 25. Use of Numbers, without Symbols, for Common Parts

AUXILIARY SYMBOLS FOR MATERIALS.—Auxiliary symbols for materials can be constructed for purposes of production planning and control in a manner similar to that shown in Fig. 22 for parts. Typical symbols or abbreviations of this kind are given in Fig. 26. These abbreviations can be used as auxiliary designations in classifications of

Material Name	Symbol	Material Name	Symbol
Aluminum	Al.	Porcelain	Porc.
Asbestos	Asb.	Rubber	Rub.
Babbitt	Bbt.	Shellac	Shel.
Brass, Half Hard	Br. ½ Hd.	Slate	Sl.
Brass Strip	Br. Str.	Solder	Sol.
Bronze, Phosphor	Brz. Ph.	Steel, Cold Rolled	S. Cr.
Canvas	Cnv.	Steel, Drop Forged	S.D.F.
Cast Iron	C. I.	Steel Plate	S. Pl.
Copper	Cu.	Steel Stamping	S. Stp.
Copper Sheet	Cu. Sh.	Tin	Tin
Fiber	Fbr.	Thread	Thd.
German Silver	Ger. Sil.	Varnish	Var.
Glass	Gl.	Wire, Brass	W.B.
Lacquer	Lac.	Wire, Copper	W.Cu.
Lead	Ld.	Wire, Drawn	W.D.
Leather	Lthr.	Wire, Galvanized	W.Galv.
Malleable Iron	Mal. I.	Wire, Music	W.Music
Nickel Steel	N. S.	Wrought Pipe	Wrt.P.
Paint	Pnt.		

FIG. 26. Names of Materials and Corresponding Alphabetic Symbols

stores and materials such as those described in the foregoing paragraphs of this Section.

OPERATIONS.—Operations can be symbolized by means of appropriate abbreviations much in the same manner as illustrated for parts and materials. Typical symbols of this kind for purposes of production planning and control are given in Fig. 27.

Operation Name	Symbol	Operation Name	Symbol
Acid Dip	A/D	Glaze	Glz.
Anneal	Anl.	Hand mill	Ha/ml.
Arc weld	Arc/w	Heat	Ht.
Babbitt	Bbt.	Heat and Bend	Ht/Bnd.
Band saw	Ba/sw	Heat-treat	Ht/tr.
Bench work	B/w	Impregnate	Imp.
Bend	Bnd.	Insulate	Ins.
Blank	Blk.	Key Seat	K/S
Bore	Bo.	Knurl	Knl.
Braid	Brd.	Label	Lbl.
Braze	Brz.	Layout and Check	L/O/Ch.
Broach	Bro.	Melt	Mlt.
Bulldoze	Bdz.	Mold	Mld.
Butt mill	B/m	Notch	Nch.
Butt weld	B/w	Number	No.
Cadmium plate	Ca/pl.	Pack	Pk.
Caulk	Clk.	Pickle	Pkl.
Center punch	C/p	Plane	Pln.
Chip	Ch.	Polish	Pol.
Chip and File	C/F	Punch	Pu.
Clean	Cln.	Reassemble	Reasm.
Cold planish	Cd/pla.	Remove burr	Rmv/br.
Convey	Cnv.	Repair	Rpr.
Counterbore	C/B	Retape	Re-tpe.
Countersink	C/S	Rivet	Rv.
Crimp	Crp.	Rough Bore, Turn and Face	Ro.B.T.F.
Cut teeth	C/tet.	Rough mill	Ro/m
Cut to length	C/l	Saw	S
Cut to suit	C/Su.	Scrape	Scp.
Design	Dsgn.	Sharpen	Srpn.
Dip	Dip	Sherardize	Sher.
Dip and tin	Dp/tn.	Shrink	Shk.
Disassemble	Disasm.	Slit	Slt.
Dismantle	Dsmt.	Solder	Sol.
Drill	Dr.	Spline mill	Spl/m
Drill and Burr	D/B	Spot Face	S/F
Drill, Ream, and Burr	D/R/B	Straddle mill	Str/m.
Electric weld	El/w.	Strip	Strp.
Emboss	Emb.	Swage	Swg.
Engrave	Engr.	Tap	Tp.
Face	Fc.	Thread	Thd.
File	Fi.	Tumble	Tmb.
Flange	Flg.	Turn and Face	T/F
Forge	Fge.	Varnish	Var.
Galvanize	Glv.	Wash	Wsh.
Gage	Ga.	Weigh	Wgh.

Fig. 27. Operation Names and Alphabetic Symbols

SMALL TOOLS.—Small tools may be symbolized for the records of production planning and control either by abbreviations formed in a manner similar to that of Figs. 22, 26, and 27, or by a mnemonic system, as outlined under the tool classification method covered in preceding pages of this Section.

MACHINES AND OTHER EQUIPMENT.—In symbolizing machine tools it is accepted practice to give the type and description, size, name of manufacturer, and the symbol. An illustration of this practice is shown in Fig. 28 which lists a few of the more typical machine tools.

Type	Description	Size	Maker	Symbol
Milling Machine	Horizontal	#0	Giddings & Lewis	GL BH0
Milling Machine	Horizontal	6-in.	Newton	New BH6
Milling Machine	Precision	#30	Universal	Univ B30
Boring Mill	Vertical	48-in.	Bullard	Bul BV48
Boring Mill	Vertical	96-in.	Cincinnati	Cin BV96
Boring Mill	Vertical	144-in.	Sellers	Sel BV144
Broaching Machine..	Horizontal	#3	Lapointe	Lp Bro3
Centering Machine...		2-spindle	Whiton	Wh Cn2.
Drill Press	Multiple	9-spindle	Natco	Na D9
Drill Press	Multiple	20-spindle	Bausch	Ba D20
Drill Press	Radial	5-ft.	American	Am. DR5
Grinder	Cylindrical	#3	Brown & Sharpe	B&S G3
Grinder	Surface		Pratt & Whitney	P&W GS
Gear Shaper		#6	Fellows	Fel. GS6
Lathe	Engine	14-in.	Lodge & Shipley	L&S L14
Turret Lathe	Automatic	6A	Potter & Johnson	P&J TA6A
Milling Machine	Horizontal	#1-B	Milwaukee	Mil MH 1B
Milling Machine	Horizontal	#4	Kempsmith	Ken MH4
Milling Machine	Spline		Pratt & Whitney	P&W MSpl.
Planer		48-in.	Niles	Nil Pl 48
Planer		60-in.	Gray	Gray Pl 60
Punch Press		50-ton	Ferracute	Fer PP C5
Punch Press	Automatic feed	450-ton	Bliss	BL PP 78½
Riveter	Hydraulic	20-ton	Hanna	Han Riv. Hy.
Screw Machine			Warner & Swasey	W&S SMa
Screw Machine	Automatic	#4¼	Gridley	Grid. SMa. A4¼
Shaper		20-in.	Gould & Eberhardt	G&E Sha 20
Slotter	Vertical	36-in.	Bement	Bem. Slo36

FIG. 28. Machine Tool Symbols Showing Type, Description, Size, and Maker

Machine symbols may also be made up of the general symbol of the operation performed on the machine and an abbreviation of the manufacturer's name. Symbols of this kind, developed by Bigelow for use in knitting mills, are given in Fig. 29. In this list of equipment, reference to makers could be readily omitted. The references are included here because in many plants similar machines may be used by different manufacturers.

Examples:		
Card	Saco Lowell	CdSL
Card	Whitin Machine Co.	CdW

Individual machines are designated by serial numerical suffixes.

The group of symbols shown in Fig. 30 was selected from a table having 77 items and symbols. In the case of knitting machines, a numerical symbol is added to the machine symbol to indicate the size of the head and the cut.

Machine	Manufacturer	Symbol
Picker	Kitson	PkK
Comber	Whitin Machine Co.	CbW
Ribbon	Whitin Machine Co.	RWW
Slubber	Saco Lowell	R2SL
Speeder	Saco Lowell	R4SL
Overedge: Car. Cuff	Merrow	OCM
Shoulder Machine	Wilcox & Gibbs	SrWG
Tubing Machine	Metropolitan	TgMn
Neck Stitcher	Union Special	SNUS
Crossing Machine	Union Special	CsUS
Button Stay: L. Mach.	Union Special	BSUS-L
Bind: Neck Machine	Union Special	BgUS-N
Patch Machine	Rose Label	PhRL
Button-hole	Singer	BHS
Cuff Presser		PC

FIG. 29. Machine Symbols for the Knitting Industry

Example: Wildman Knitter, 16 head, 8 cut KtW16-8.

Machine	Manufacturer	Symbol
Skein Winder		SWd
Winder	Payne	WdP
Knitter, Rotary	Cotton	KtRCn
Rubber Cover Mill		RC
Looper	Record	LpR
Loader	Palmer Bros.	LP
Extractor	Tolhurst	XT
Spreader	McCreary	SdM
Cutter	Eastman	CtE
Merrow: Gussets	Merrow	MGM

FIG. 30. Machine Symbols for Underwear Manufacture

PRODUCTION CENTER SYMBOLS.—Production centers, or work stations, are frequently designated for purposes of production planning and control by a number which may include the designation of the building and the floor upon which the department is located. In case the arrangement of the plant is exclusively by production centers, the designation may be an abbreviation of the name of the product produced. Similarly, if plant arrangement is by the one-shop plan, the production center designation may be an abbreviation of the name of the principal operation performed.

SECTION 21

PRINCIPLES OF MANAGEMENT

CONTENTS

SECTION 21

PRINCIPLES OF MANAGEMENT

STATEMENTS OF PRINCIPLES.—Formulation of the principles today accepted as underlying effective management dates in America largely from the time of Frederick W. Taylor and Henry L. Gantt, pioneers in scientific management. Other formulations which are well known are those of Henri Fayol, French industrial engineer, in a brief summary of principles of administration, and L. P. Alford's statement of some 50 "Laws of Management." These various statements of principles are summarized in this Section.

While by no means all-inclusive, this summary constitutes a representative statement of the generally accepted principles of management. They definitely connect cause with effect, or formulate an established trend and so indicate what results may be confidently expected from a certain course of action. They aid in checking policies, plans, procedure, and methods, and they help avoid fundamental mistakes.

In their nature, the principles cannot have the exactitude of physical laws. It must be remembered that the first attempts to formulate general principles seem to have been directed not so much toward completeness of survey as toward expressing the knowledge at hand in a minimum number of statements (Alford). The conditions in Taylor's time, for example, were not those of today, and his statements reflect his problems, such as inducing workers to earn more than the traditional day-wage and showing management's responsibility for planning the work so that this could be done. This does not affect the fundamental character of his ideas, but it does show in their expression. As another illustration, modern labor unionism tends to make the operation of the law of supply and demand in connection with wages more sluggish. Making allowance for such considerations as these is obviously necessary in applying the principles to practical management.

Taylor's Principles of Scientific Management

FUNDAMENTAL FACTORS.—Frederick W. Taylor stressed the importance of principles and formulated these four, which are known as his **principles of scientific management.** They are:

1. The development of a true science.
2. The scientific selection of the workman.
3. His scientific education and development.
4. Intimate, friendly cooperation between the management and men.

H. S. Person, a leading exponent of the Taylor system of scientific management, interprets Taylor's principles as follows, characterizing

scientific management as distinguished from merely systematized management.

1. The use of research, investigation and experiment (with their processes of analysis, measurement, etc.) in determining and appraising the facts of managerial situations; and the use of these facts in establishing objectives, policies, projects, plans, and procedures.
2. The substitution of the known for the unknown, the constant for the variable, i.e., the establishment of standard factors in the managerial situation in terms of which may be made calculations and plans which may be expected to come true.
3. The establishment of a control which directs the researches, establishes and maintains the standards, makes the plans and controls coordinated efforts for consummation of the plans.

Subordinate to and supporting these principles or rules are many others, such as the exception principle, the separation of design and execution, the securing of workers' goodwill, the recording of process methods, etc.

SIX GROUPS OF PRINCIPLES.—Taylor's writings present many more fundamentals that can be stated in the form of principles or rules. To round out his teachings in this regard, certain principles or rules, selected from his two published works (Shop Management, and Principles of Scientific Management), have been assembled into six groups:

Industrial Organization	Foremanship
Methods and Times for Doing Work	Relations with Workmen
Economic Operation and Costs	Wages and Wage Plans

As presented below, they are, in the main, in his precise language. Here and there paraphrasing has been resorted to in the interest of economy of space, and in some cases concepts taken from more than one page have been combined to round out the statement. Sometimes the terms do not have the same connotation as they do today.

Industrial Organization.—1. For effective functioning of manufacturing organization,

a. Relieve workmen, gang bosses, and foremen, of the work of planning.
b. Confine the work of each man to the performance of a single leading function.
c. Provide a sufficient number of leading men. (Shop Management.)

2. In performing complicated work a good organization with a poor plant will give better results than the best plant with a poor organization. (Shop Management.)

3. To reorganize a manufacturing concern successfully,

a. Choose the general type of management.
b. Expend enough money to complete the changes.
c. Take enough time to get worthwhile results.
d. Make the changes in a sequence which will maintain quality of product and avoid labor troubles. (Shop Management.)

Methods and Times for Doing Work.—1. With accurate time knowledge as a basis, surprisingly large results can be obtained under any plan of management. (Shop Management.)

2. The productivity of a workman is increased by measuring his per-

formance against standard at frequent intervals, informing him of his progress, and assisting him if he falls behind. (Shop Management.)

3. Complete standardization of all details and methods is indispensable to specifying the proper time in which each operation shall be done, and to insisting that it shall be done in the time allowed. (Shop Management.)

Economic Operation and Costs.—1. To unite high wages and low labor costs,

a. Assign to each workman a clearly defined task.
b. Provide each workman with such standardized conditions and appliances as will enable him to accomplish his task with certainty.
c. Remunerate each workman with large pay when he accomplishes his task.
d. Make sure when a workman fails he will be the loser thereby. (Shop Management.)

2. The greatest permanent prosperity for workman and employer comes from doing work with the smallest expenditure of human effort, natural resources, and invested capital. (Principles of Scientific Management.)

3. The cost of production is lowered by separating the work of planning and the brain work, as much as possible, from manual labor. (Shop Management.)

4. For efficient operation the whole works should be managed by the planning department. (Shop Management.)

5. For effective management the manager should receive only condensed, summarized, and invariably comparative reports. (Shop Management.)

Foremanship.—1. For efficient operation each man, from the assistant superintendent down, should have as few functions as possible to perform. (Shop Management.)

2. For efficient operation gang bosses and foremen should be entirely relieved of the work of planning. (Shop Management.)

3. To make foremanship more effective machinery should be grouped according to the one-shop plan. (Shop Management.)

4. Deterioration in the quality of product produced under incentive wage payment can be prevented by a system of overinspection. (Shop Management.)

Relations with Workmen.—1. Each act of every workman in the mechanic arts requires the application of so much science that the responsibility for doing the work must be almost equally divided between the management and the workman. (Principles of Scientific Management.)

2. To perform work according to scientific laws almost every act of a workman should be preceded by preparatory acts of the management to enable him to do his work better and quicker than he otherwise could do. (Principles of Scientific Management.)

3. The obstacles to maximum output are swept away by close, intimate personal cooperation between the management and the workmen. (Principles of Scientific Management.)

4. Immense help is afforded a workman by scientifically selecting, training, teaching, and developing him to do his work. (Principles of Scientific Management.)

5. In doing laboring work it is possible for a workman to be under load only a definite percentage of a day for maximum efficiency. (Principles of Scientific Management.)

6. To deal successfully with men,

a. What is demanded of them must be entirely just and such as can be surely accomplished.
b. Exact and detailed direction should be given to the workman, telling him what he is to do and how he is to do it.
c. At the start of the work, the energies of the management should be centered upon one single workman.
d. If the workman fails, the management should demonstrate that the work can be done as called for. (Shop Management.)

Wages and Wage Plans.—1. That the employee may earn high wages, and the employer operate at low labor costs,

a. Each workman should be given, as far as possible, the highest grade of work that he can do.
b. He should be called upon to turn out the maximum work which a first-class man can do and thrive.
c. For doing this he should be paid above the average. (Shop Management.)

2. For successful operation of an incentive wage plan, each workman should be able to measure each day's performance against his earnings. (Shop Management.)

3. To maintain earnings and satisfaction in operating an incentive wage plan, each workman's performance should be measured by itself. (Shop Management.)

Gantt's Principles of Industrial Management

SIMILARITY TO TAYLOR'S PRINCIPLES.—Henry L. Gantt, like Taylor, emphasized the importance of principles in developing, maintaining, and operating an industrial concern. From his three books —Work, Wages and Profits, Industrial Leadership, and Organizing for Work—have been drawn the principles presented below. They are arranged in six groups, with the same headings used immediately above for Taylor's Principles of Scientific Management.

Industrial Organization.—1. The efficiency of an organization appears to be in direct proportion to the success of introducing the method of equal opportunity for selecting leaders. (Industrial Leadership.)

2. The authority to issue an order involves the responsibility to see that it is properly executed. (Industrial Leadership.)

3. Intrinsic authority is a possession of an executive who knows what to do and how to do it. (Organizing for Work.)

4. A wise policy is of more avail than a large plant, good management than perfect equipment. (Industrial Leadership.)

5. We have no right, morally, to decide as a matter of opinion that which can be determined as a matter of fact. (Industrial Leadership.)

6. Actions based on opinion will lose in competition with actions based on facts. (Industrial Leadership.)

Methods and Times for Doing Work.—1. All activities can be measured by the amount of time needed to perform them. (Organizing for Work.)

2. Scientific investigation of a question involving human labor must,

a. Find out the proper day's task for a man suited for the work.
b. Find out the compensation needed to induce such a man to do a full day's work.
c. Plan so that the workman may work continuously and efficiently. (Work, Wages and Profits.)

3. The most efficient method of doing any piece of work cannot be devised with certainty until the method has been subjected to a complete scientific investigation. (Work, Wages and Profits.)

4. The most complete analysis that can be made of the working of a plant, one that enables the management to see each day how orders are being carried out, is made from the daily records of man-performance. (Work, Wages and Profits.)

5. Workmen do not object to a change in the set time for doing work, provided the new time corresponds to a new set of instructions which will enable them to perform the work in the time set. (Work, Wages and Profits.)

6. A man in a large gang does not work as efficiently as when he works individually, or in a small gang. (Work, Wages and Profits.)

7. A workman who is supplied with proper implements and given intelligent direction can do at least three times as much work as the average workman, if the limiting factor is physical exertion. (Work, Wages and Profits.)

8. Well-thought-out plans, accompanied by complete instructions, often produce more than 100% more than is commonly done. (Work, Wages and Profits.)

Economic Operation and Costs.—1. A high degree of efficiency is obtained from careful scientific analysis and investigation. (Work, Wages and Profits.)

2. Misdirected effort is simply loss and must be borne by either the employer or the employee. (Work, Wages and Profits.)

3. Large profits can be permanently secured only by efficient operation. (Work, Wages and Profits.)

4. A system of management based on the scientific method is as much an asset as plant or equipment. (Work, Wages and Profits.)

5. The output of a factory should not bear the total expense of the factory, but only that portion of the expense needed to produce it. (Industrial Leadership.)

6. The costs of being idle, whether of men or machines, are almost as much as the cost of being at work. (Organizing for Work.)

Foremanship.—1. Through intelligent direction the output per man may be largely increased without a corresponding increase in expense. (Work, Wages and Profits.)

2. Giving the foreman a financial interest in teaching the individual workman changes the foreman from a driver of his men to their friend and helper. (Work, Wages and Profits.)

Relations with Workmen.—1. Any plan of management to be permanently successful must be beneficial alike to employer and employee. (Work, Wages and Profits.)

2. The first step in increasing the efficiency of a plant is for the management to convince the workmen of its good faith, and determination to treat all workmen fairly. (Work, Wages and Profits.)

3. Greater and more stable results can be obtained from a policy of teaching and leading workmen to do their work than from a policy of driving and forcing. (Work, Wages and Profits.)

4. Habits of industry are far more valuable than any kind of knowledge or skill. (Work, Wages and Profits.)

Wages and Wage Plans.—1. An employer can afford to pay big wages to a group of efficient, harmoniously working men. (Work, Wages and Profits.)

2. The efficient workman at high wages is much more profitable to his employer than the inefficient man at low wages. (Work, Wages and Profits.)

3. To assure the performance of the amount of work a workman can do, offer proper wages for its successful completion, and furnish an instructor to teach the workman how to do it. (Work, Wages and Profits.)

4. A workman should be given no increase in wages over day rate unless a certain degree of efficiency is maintained. (Work, Wages and Profits.) The base day rate should be guaranteed.

5. The additional amount of compensation needed to make men do as much as they can, varies from 20% to 100% of what they can earn when working by the day, according to their own methods and at their preferred speed. (Work, Wages and Profits.)

6. Penalizing a good workman in proportion to his increased effort is to discourage him and ultimately to influence him to limit his output to that of a poor workman. (Work, Wages and Profits.)

7. The task and bonus system of wage payment creates a strong spirit of harmony and cooperation because,

a. It determines by an expert the best method and shortest time for doing the work with the appliances to be had.
b. It develops a standard method for doing the work, and sets a maximum time which a good workman needs to accomplish it.
c. It finds a capable workman who can do the work in the time and manner set, or it teaches an ordinary workman how to do it.
d. When high efficiency is obtained, it compensates liberally the workman and those who enable him to maintain the efficiency specified by supplying him with materials and appliances.
e. It recruits for the corps of experts from those who have learned the best ways of doing work and so makes the system self perpetuated.
f. It selects the best expert mechanic to teach the best method to the workmen; it does not call upon the ordinary foreman to do the work of an expert. (Work, Wages and Profits.)

8. A task that is within the power of a workman to accomplish without overexertion is pleasant and not tiring, increases the keenness of perception, and causes mental exhilaration. (Work, Wages and Profits.)

9. A task so severe that few can attain it is of no advantage, for few will continue to strive for a reward which they cannot reach. (Work, Wages and Profits.)

10. Setting a proper task for a workman imposes obligations on the management to see that the conditions under which the task was set are maintained. (Work, Wages and Profits.)

11. The bonus changes the frictional lag due to inertia into an acceleration. (Work, Wages and Profits.)

Holden's Principles of Policy Determination

DEFINITION OF POLICY.—Basic to any successful undertaking are sound policies. Policies may be defined as those precepts by which all administrative and operating decisions are determined so that the progress and development of the enterprise will be properly directed toward definite objectives.

POLICY DETERMINATION.—Setting of policies is a primary function of administration and should be accomplished with due regard to the following principles which were formulated by Paul E. Holden, Professor of Industrial Management, Stanford University:

1. The statement of any policy should be definite, positive, clear, and understandable to every one in the organization.
2. Policies should be translatable into practices, terms, and peculiarities of every department or division of the enterprise.
3. Policies, regardless of how fundamental, should not be inflexible: they should, however, possess a high degree of permanency.
4. Stability of policies is essential and constantly changing policies are fatal to business success.
5. There should be as many policies as necessary to cover conditions that can be anticipated but not too many policies to become confusing or meaningless.
6. Policies should be predicated on fact and sound judgment and should not constitute merely personal reflections.
7. Policies should not prescribe detailed procedure except in rare instances.
8. Policies should recognize economic principles, be in conformity with federal and other laws and be compatible with the public interest.

Fayol's Principles of Industrial Administration

ADMINISTRATIVE PRINCIPLES.—The thirteen principles of administration recognized by Henri Fayol (Industrial and General Administration) are these:

Division of Labor.—Division of labor is a law of nature. . . . The object of division of labor is to produce more and better results with the same amount of effort. The workman who is always making the same part, and the manager who is constantly dealing with the same problems, acquire a skill, certainty, and accuracy which increase their output. On the other hand, every change of occupation involves an effort of adaptation, which reduces production.

Authority and Responsibility.—Authority is the right to command and the power to make oneself obeyed. We find that it is of two kinds, statutory authority which belongs to a position, and personal authority which is the result of intelligence, knowledge, moral qualities, and the

gift of commanding men. A man cannot be a good leader unless he has personal as well as statutory authority.

We cannot conceive of authority without responsibility; that is to say, a "sanction," a reward or a penalty, which accompanies the exercise of power; responsibility is a natural consequence of authority and follows whenever authority is exercised. The need for a "sanction" arises in the first place from a sense of justice, and it is made greater by the fact that, for our common good, we must encourage all operations which are successful and discourage those which are not.

Discipline.—Discipline consists of obedience, diligence, energy, correct attitude, and outward marks of respect, within the limits fixed by the agreement between a concern and its employees. This agreement always determines the conditions of discipline, no matter whether it has been freely discussed or not, is written or understood, and is the result of the wishes of the parties concerned or simply of laws and customs. Since it is governed by many different kinds of agreements, discipline itself naturally appears in many forms, and the obligations which it entails in the way of obedience, diligence, and energy vary in different concerns, for different classes of employees in the same concern, and also according to time and place.

Unity of Command.—An employee must receive instructions about a particular operation from one man only. This is the rule of unity of command, a rule which applies at all times and under any circumstances, and whose influence on business success is at least as great as that of any other principle; if this rule is broken, authority is weakened, discipline is endangered, order becomes confusion, and stability is threatened.

Unity of Management.—This principle may be expressed as follows: One manager and one plan for all operations which have the same object in view. It is an essential condition for unity of action, for coordinating all one's resources, and for seeing that all efforts are directed towards the same end. A body with two heads is just as much of a freak in the world of organization as it is in the animal world, and it is equally difficult for it to survive.

Subordination of Individual Interests to the Common Good.—This principle reminds us that in any undertaking the interest of an employee, or a group of employees, must not take precedence over the interest of the concern as a whole; this is equally true for undertakings of every kind from the home to the State.

Remuneration of Staff.—Remuneration is the reward for work done; it must be on a fair basis, and must, as far as possible, be satisfactory to both employer and employed.

Centralization.—Centralization, like division of labor, is one of the laws of nature; in every organism, whether it is animal or social, sensations converge toward the brain or management, and from this brain or management are sent out the orders which set in motion all parts of the organism. Centralization is not a system of administration, which is good or bad in itself, and can be adopted or discarded at will; it is always present to some extent, so that the question of centralization is simply one of degree—the problem is to find out what is the best degree of centralization for a given undertaking.

Hierarchy.—The hierarchy is the series of officials which runs in order of rank from the supreme authority to the lowest employee. The hierarchic channel is the road which all communications, leaving from or addressed to the supreme authority, follow in passing through all the ranks of the hierarchy.

Order.—Every one knows the formula for order in material things: "A place for everything, and everything in its place"; and the formula for human order is the same: "A place for everyone, and everyone in his place."

Equity.—In order to encourage the staff to put all the goodwill and devotion of which it is capable into the exercise of its duties, we must treat it with friendliness, and equity is the result of combining friendliness with justice. This, however, does not mean that equity excludes either energy or sternness when these qualities are needed, and its application calls for a great deal of experience, common sense, and kindness.

Stability of Staff.—An employee requires time to settle down to a new function and to reach the point where, if he has the necessary ability, he will perform it satisfactorily; if he is displaced as soon as or before the period of initiation is complete, he will not have had time to render any appreciable service, and if this is continually happening, the function will never be satisfactorily performed.

Esprit de Corps.—Unity is strength. This proverb should be considered by the head of every undertaking. Harmony and unity among the staff of a concern are a source of great strength, and we must, therefore, see that they are developed.

Alford's Principles of Manufacturing Management

Alford has formulated principles of manufacturing management which classify conveniently into eight groups. The original presentation was to the American Society of Mechanical Engineers and published by that Society (Trans. A.S.M.E., vol. 48). They also appear in slightly modified phraseology and with certain additions to the original group, in Laws of Management Applied to Manufacturing, and Principles of Industrial Management.

ORGANIZATION AND LEADERSHIP.—The first group of these principles concerns the structure of organization, leadership, and executive work.

The Undertaking.—The necessary preliminary to all corporate activity is a clear, complete statement of the object of the activity, formulated as a policy or set of instructions; the resulting action must subordinate all secondary considerations to that of the stated object.

The Objective.—Each part and subdivision of the organization should be the expression of a definite purpose in harmony with the objective of the undertaking.

Authority and Responsibility.—Responsibility for the execution of work must be accompanied by the authority to control and direct the means of doing the work.

No other principle of industrial operation has had such general acceptance. Authority emphasizes power over a situation or over an individual. Responsibility emphasizes answerability for the fulfilment of a function or activity to some person or in some situation. This fundamental is sometimes called the principle of correspondence.

Ultimate Authority.—The responsibility of a higher authority for the acts of its subordinates is absolute.

Formal Authority.—A clear line of formal authority must run from the top to the bottom of an organization for control.

The Span of Control.—The number of supervisory subordinates reporting to a superior should preferably be limited to no more than five or six. The number of workers reporting to a group leader or foreman should be no more than ten to twelve.

Exceptions.—Managerial efficiency is greatly increased by concentrating attention solely upon those executive matters which are questions of policy, or are variations from routine, plan, or standard.

Assignment of Duties.—The duties of every person in an organization should be confined as far as possible to the performance of a single leading function.

Written Definition.—The duties, authority, responsibility, and relations of everyone in the organization structure should be clearly and completely prescribed in writing.

Coordination.—The smooth, frictionless, effective attainment of the objective of an organization is secured through the coordination of all the activities performed.

Fact Control.—The principle of fact control in industrial administration and management is: Any fact gains its real significance through its relation to all other facts pertaining to the situation.

Homogeneity.—An organization to be efficient and to operate without friction should bring together only duties and activities that are similar or are directly related.

Organization Effectiveness.—The final test of an industrial organization is smooth and frictionless operation.

Leadership.—Wise leadership is more essential to successful operation than extensive organization or perfect equipment.

Tead has given this definition of leadership (Taylor Soc. Bul. 12):

> . . . that combination of qualities by the possession of which one is able to get something done by others chiefly because through his influence they become willing to do it.

SPECIALIZATION AND STANDARDIZATION.—There are four principles of specialization and one of standardization.

Division of Work or Specialization of the Job.—Subdividing work so that one or a very few manual or mental operations can be assigned to a worker improves the quality and increases the quantity of output.

Division of Effort or Specialization of the Individual.—Assigning to each worker one or a very few manual or mental operations which he is

particularly adapted to perform improves the quality and increases the quantity of output.

Corollary. Functional Management (Functional Foremanship) or Specialization of the Management.

As the scope of an executive's responsibility is narrowed his efficiency increases.

Transfer of Skill or Specialization of Tools and Machines.—The attention and skill required to use a tool or operate a machine is inversely as the skill transferred into its mechanism.

Simplification or Specialization of Product.—Concentrating upon the manufacture of a single or a few types and sizes of product tends to improve the quality and lower the production cost.

An example of the possibilities of **improvement by specialization of the job** is given by Parkhurst:

From an extensive accumulation of statistics and records, covering thousands of cases in my experience, I have been able to summarize the efficiency of several groups of workers. But before presenting these facts, let it be understood that the low efficiencies disclosed are in no way a reflection on the employees. They reflect rather the fault of the management.

The following low efficiencies of workers on unstandardized tasks generally prevail:

1. The **unskilled worker** and those doing routine clerical jobs, working generally in small groups and under average good supervision, are found to be 50% efficient.

This is the result in a small group directly supervised.

2. The **average machine operator**, or man doing a routine job with certain more or less fixed and perhaps mechanically controlled equipment, is found to be 38% to 40% efficient.

The reason for this low efficiency is that after the man receives his initial (and, more often than not, incomplete) instructions, it is assumed that his more or less mechanically controlled job requires little supervision and follow-up. Generally speaking, there are more men of this class under one supervisor than in class 1.

3. The **general all-round mechanic** or journeyman hired to do a variety of work, supposed to be competent, hence requiring less supervision and left to plan most of his work and often to find ways and means of doing it, is found to be 30% efficient.

The cause of his low efficiency lies in the greater variety of his work combined with the fact that he must perform a number of different operations, often in several different places or with different machines for which he must also collect the needed tools. In other words his job, generally speaking, is not so well supervised or controlled. This same man, however, working under standardized conditions and benefiting by facilities contributed through better management, is quick to profit when the opportunity is offered to increase his output as well as his pay.

4. The **highly skilled all-round man**, toolmaker, tool designer, tool draftsman, die sinker, patternmaker, and men of this class are but 25% to 28% efficient.

Such men are inefficient because they receive a minimum amount of detailed instruction and supervision. They are the highest paid and considered the most skilled and are supposed to be able to do their work in the best way and in the shortest time.

These **comparative efficiencies** are based on average performance without any major changes in the equipment or method of doing the work. They therefore reflect the result of the predetermination of a proper standard coupled with an incentive to interest the workman in doing his full share toward increased production. The comparisons are all based on former daywork efficiencies. In the case of piecework or premium work, the author's experience shows that such work on the average is only about 70% efficient.

Standardization.—Predetermined results, established procedures, and fixed types, sizes, and characteristics of product, improve operation and reduce cost of manufacture.

Corollary 1. **Interchangeable manufacture** reduces manufacturing cost and, all other characteristics being equal, produces a product of maximum serviceability.

PRODUCTION PLANNING AND CONTROL.—Because of the complexity of the functions of production there are numerous principles that classify under the groups devoted to production planning and control.

Work Assignment.—A reasonable work assignment is an amount of work to be done in a given time, for a wage mutually satisfactory to worker and management, and capable of being performed by a worker of average skill in the time specified with an amount of free time sufficient for personal needs and for the relief of fatigue.

Economic Production.—1. Production at **Increasing** Relative Rate. The unit cost of production decreases when the rate of increase in output increases faster than the rate of input or use of the production factors.

2. Production at **Decreasing** Relative Rate. The unit cost of production increases when the rate of increase in output increases at a slower rate than the rate of input or use of the production factors; and the unit cost of production increases when the rate of output decreases and the rate of input or use of the production factors increases.

Corollary. For the same percentage change, the production factor "labor" alone has three times the effect on production as the production factor "fixed capital" alone.

Mass Production.—1. Large-scale production tends to increase operating efficiency and competitive power.

2. In large-scale production the unit time of production tends to approach the actual operating time as a limit.

Simultation or Coordination.—1. The minimum over-all production time for a group of operations, or for the operations on an item of product, is obtained by the maximum overlapping, or simultaneous performance, of the several work units.

2. The minimum over-all production time for a group of simultaneous operations tends to approach the time of the longest work unit as its limit.

Planning or Mental Labor.—The mental labor of production is reduced to a minimum by planning before work is started, what work shall be done, how the work shall be done, where the work shall be done, and when the work shall be done.

Production Control.—The highest efficiency in production is obtained by producing the required quantity of product, of the required quality, at the required time, by the best and cheapest method.

Operating Performance.—Operating performance is controlled most directly through control of the rates of expenditure of labor, materials, and expense. (Alford and Hannum.)

Indirect Expense.—The indirect expense chargeable to the output of a factory should bear the same ratio to the indirect expense necessary to run the factory at normal capacity, as the output in question bears to the normal output of the factory.

Manufacturing Cost.—Only those expenditures and charges which have made an essential contribution to the production of a manufactured item shall be allocated to the cost of that item.

MATERIALS CONTROL AND HANDLING.—The principles of materials control and handling relate to procurement, storing, and moving of materials and parts as a facilitation to production.

Materials Control.—1. The highest efficiency in the utilization of materials is obtained by providing the required quantity, of the required quality and condition, at the required time and place.

2. The highest efficiency in the storage of materials, tools, and supplies is obtained by providing a definite place to store every item, keeping every item in its assigned place, and keeping an adequate record thereof.

3. Quickening material turnover reduces the expense of material control.

Flow of Work.—The greatest economy in progressing materials through a manufacturing plant is secured when the materials move a minimum distance in passing from operation to operation.

Handling Materials.—1. Economy in the control of work in process (materials in process) is increased by reducing to a minimum the time for banking and handling materials.

2. Economy in handling materials is increased by moving them in a straight line.

3. All other factors being constant, handling materials by gravity is more economical than handling by power.

4. Economy in handling materials is improved by increasing the proportion of use time to idle time of the transporting unit.

5. Economy of handling materials is increased by increasing the speed of the transporting unit to the point where the cost of securing the increased speed is equal to the resulting savings in handling costs.

6. The productivity of mobile materials handling equipment units is increased by providing smooth floors, wide aisles, easy turns, and ample approaches to doorways and elevators.

7. Economy in handling materials is increased by replacing equipment and methods with more efficient equipment and methods, when

the cost of replacement is less than the resulting savings accumulated over a reasonable period of time.

8. The unit cost of handling materials decreases as the quantity handled increases up to the capacity of the transporting unit.

PRODUCT INSPECTION AND QUALITY CONTROL.—There are four important principles distinguishable in this group:

1. The **quality of manufactured goods** is a variable with an upward trend under conditions of competitive manufacture.
2. **Control of quality** increases output of salable goods, decreases costs of production and distribution, and makes economic mass production possible.
3. The **inspection function** in manufacturing (measuring and judging production) for highest efficiency must be independent of, but coordinate with, the functions of engineering, production, and sales.
4. The **conformance of finished product to its design specifications and standards** should be accomplished by avoiding the making of nonconforming material rather than by sorting the good from the bad after manufacture is completed.

INDIVIDUAL PRODUCTIVITY.—The process of specialization whereby the effort of the worker is concentrated on a single or a very few operations has led to an extensive study of the methods and conditions of doing work with the purpose of finding the "one best way." Several able investigators have conducted research in this field, notably Frank B. and Lillian M. Gilbreth. A group of fundamentals dealing with motions has been discovered and established largely through experiment. These therefore have had a somewhat different development than other operating fundamentals.

Productivity of the Individual Worker.—The highest individual productivity is possible only when the worker is given the highest class of work for which his natural abilities fit him.

Taylor repeatedly stressed this law. Hartness (Human Factors in Works Management) has given similar emphasis to this fundamental:

> The welfare of all men, from the Napoleons of industry to the newest recruit into the work, should be so considered that each man should have the best work for which his endowment and general characteristics fit him.
>
> We lift up a man when we take a worker whose greatest achievement has been to handle a shovel inefficiently and by patience teach him to do a better work; one by which he creates more value, and one in which he can obtain a better wage for himself and family. If his brain is not made to guide a nation, this work may not be so degrading as it may seem. The work for each should be the highest type available for him.

Development of Skill.—In the development of skill, the qualities of speed and accuracy are acquired through the process of learning. The principles of these three factors are stated as follows:

1. **Speed (or facilitation).** As the newly acquired nerve path is strengthened, the new response tends to proceed more rapidly.

2. **Accuracy (or elimination).** As the new connections between impressions and memories improve, there are fewer useless and erroneous movements, the response becomes more precise and likewise more accurate.

3. Learning. Under usual conditions an average worker acquires skill rapidly during the first half of the training period, then more slowly for a time, if at all, and finally at a rapid rate until average proficiency is attained.

Hand Motions (Gilbreth).—Frank B. and Lillian B. Gilbreth have worked out the laws of motion in doing work. The principal ones applying to motions of the hands are:

1. Both hands should work and rest at the same time.
2. Both hands should begin and complete their "therbligs" at the same instant.
3. The arms should move in symmetrical directions, whether the same or opposite.
4. The paths of fast motions should be taught and learned.
5. The sequence of fewest "therbligs" is usually the best way of doing work.

Motion Time.—Segur has developed a law of the time required to perform motions in doing manual work. He states it thus: Within practical limits the times required by all expert workers to perform true fundamental motions are constant.

WAGES AND WAGE PAYMENT.—Fundamentals of remuneration concern the bases from which wages are set, and methods that cover the application of monetary incentives and the basis of hours of work.

Wages.—1. Relative Wages. Wages tend to lower when the supply of labor exceeds the demand; wages tend to rise when the supply of labor is insufficient to satisfy the demand.

2. Wage Level. The normal wage level of each country depends upon and corresponds to that country's general average productivity of labor.

Corollary: High wages accompany high operating performance.

Task and Wage Incentive.—1. The average worker accomplishes the most when assigned a definite amount of work to be done in a given time. (Taylor.)

Taylor gave a most practical turn to the application of this law by insisting that the more elementary the worker's mind and character, the shorter should be the period of time for which work is assigned in advance.

2. A wage incentive for the accomplishment of a definite task influences a workman to maintain his maximum output.

3. Incentive wage rates must be based on such simple mathematical rules that the worker will have no difficulty in determining unaided the amount of money he earns in doing a job. (Barth.)

Base Time or Rate Change.—Base time on standardized jobs should never be changed except in those cases where a substantial change has previously been made in conditions, methods, or equipment.

The National Metal Trades Association in a booklet, Methods of Wage Payment, gives a rule which supports this law:

Rates or standards should be established only as a result of a series of accurate studies, and should be subject to such checks and rechecks before definite adoption as to make unnecessary any later change in the rate or standard as long as the job itself remains unchanged.

Practical question in applying this law is how much **change in method** or design and what **improvement in tools** and equipment justify a change in a guaranteed rate. Sylvester has answered this question in this rule:

Any change in condition which permanently increases or decreases efficiency over 15 points from the 100% mark warrants a change in incentive rate.

Payment for Results.—The amount of wages or salary paid to a worker in industry should have a direct, logical relation to the quality of work done by the worker.

Hours of Work.—Cox (The Economic Basis of Fair Wages) has formulated a law of hours of work as follows:

All other factors influencing production being constant, a decrease in the hours of work increases the leisure of the workers, an increase in the hours of work increases the comfort of the workers.

By way of further explanation Cox says:

The hours to be worked are always a compromise between greater leisure and greater comfort for the workers. This is not generally realized but is nevertheless true. Whether the schedule of working hours should be shortened or lengthened depends on whether increased leisure, or an increased consumption of the good things of life, is most desirable in the opinion of the general average.

SAFETY AND MAINTENANCE.—The principles of safety and maintenance have to do with conditions that are contributory to maximum production.

Safety.—Maximum productivity is dependent upon the reduction of accidents to an irreducible minimum. (American Engineering Council.)

Few, if any, of the laws of management in manufacturing have such a possibility of a high percentage of application as this law of safety. Heinrich gives as his matured judgment:

1. 98% of all accidents are preventable.
2. 88% of the causes of all accidents are supervisory and 10% are physical (both within the power of the employer and employee to remedy).

Maintenance.—The law of accident prevention as applied to plant and equipment, or the law of maintenance is: Anticipating repairs and replacements prevents interruption due to bad-order or broken-down equipment.

SECTION 22

MEASURES OF PERFORMANCE

CONTENTS

SECTION 22

MEASURES OF PERFORMANCE

MEASUREMENT AND COMPARISON IN INDUSTRIAL OPERATION.—Progress and improvement are determined, and their extent evaluated, only by a comparison of what was done before with what was done after a change for the better. Comparison can be made only by putting, side by side, earlier and later records expressed in the same terms and identical units. Herein arises the necessity for measurement of costs and operating results. Units and methods for accurate, impersonal measurement and comparison are the foundation for reports and statements of operation, for analysis of production performance and costs, and for quantitative determination of what must be done to bring improvement in industrial operation and in cost control. They also permit comparison of performance in one concern with those of others, and with the records of industry as a whole. They are basically important in any plant and in industrial operation, and are essential in all cost work.

Elements in Measurement.—In any measurement are four essential elements:

1. Definition of characteristic or quality to be measured.
2. Selection of standard for that characteristic or quality.
3. Determination of unit or units in which measurement is to be made.
4. Creation of accurate means (methods and instruments) to compare characteristic or quality as produced with standard selected.

The difficulty of satisfying these requirements in connection with much industrial operation is apparent because of the presence of the problem of measuring human performance by accurate means. However, numerous methods have been developed covering a wide range of industrial activity. Prominent among these methods are the following:

1. Use of performance ratios and turnovers.
2. Use of percentages.
3. Use of rates and ratings.
4. Use of experiential factors.
5. Application of methods of comparison.
6. Application of engineering efficiencies.
7. Measurement in physical quantities.

Ratios, percentages, and rates are simple mathematical quantities. **Ratings** are made use of through rating scales or evaluation sheets.

By **experiential factors** is meant values or quantities determined from experience. They are aids in setting up attainable standards of performance. Examples are: average records of tardiness, absence and

employment of industrial workers, fatigue allowances, days lost due to illness, labor turnover, and the like.

Comparisons are made in various ways, principally by tabulations, tables, and charts. Budget comparisons are a common application of tabulations and tables. Gantt charts are examples of a graphic instrument of comparison, which compares for a definite period of time planned or estimated results against actual performance. **Index numbers** are also used for the purpose of comparison; they should be used only with full knowledge of how they were compiled and the meaning they transmit.

Efficiencies and physical quantities used in measurement of operating results are of engineering origin and application. In general, they show the relation of input and resulting output of an operating factor.

Units and Formulas of Measurements

UNITS FOR MEASURING RESULTS.—To permit use of methods and factors for measuring operating results in industry, as indicated in preceding paragraphs, various units, formulas, and relationships have been developed. The table at the end of this Section lists representative examples of certain of the more important of these units with the exception of wage-payment formulas. The units of this table are in use in industrial operation with varying degrees of acceptance. Wherever a unit has an ascertainable origin, that information is given. However, this recognition is possible in only a few instances. Many of the units are ratios and percentages. The manner in which they are developed is easily applied to the formulation of other units of their general kind.

OVER-ALL OPERATING EFFECTIVENESS: DE LEEUW.—As industrial operation includes many activities and functions, an over-all measure of its effectiveness would be a combination of efficiencies of partial performances. De Leeuw defines the most efficient plant as the one that produces the greatest amount of product with the least outlay.

Let E_1 = Efficiency of plant
E_p = Efficiency of purpose (that is, greatest possible efficiency)
E_t = Total efficiency

Then $E_1 = \frac{E_t}{E_p}$

Let W = Waste (that is, that part of expended material or effort which could have been but was not utilized)

Then $W = 1 - \frac{E_t}{E_p}$

An illustration of the application of the De Leeuw formula is afforded by figures given by McKnight (Mech. Eng., vol. 54) in an analysis of incoming and outgoing freight in ten representative plants for a year's operation, as follows:

Incoming productive material.........	78,000 net tons
Outgoing finished products............	62,000 net tons

That is,

$$E_1 = \frac{E_t}{E_p} = \frac{62{,}000}{78{,}000} = 79\% +$$

$$W = 100 - 79 = 21\%$$

OVER-ALL OPERATING EFFECTIVENESS: FERGUSON. —Ferguson, although recognizing the limitations of the engineering method of analyses of effectiveness of industrial operation, contends that relative effectiveness can be estimated from three factors:

1. Organization.
2. Technical facilities.
3. Utilization of knowledge and facilities in a plant.

Let K = Organization factor
T = Technical factor
U = Utilization factor

Then $K + T + U = 100$ points

To explain more fully the make-up of these three factors: **Organization** includes the organization structure, design of personnel relations, assignment of functions and duties to departments and executives, means for promoting morale both of management and working force, and allied matters which are among the resources of management for effectiveness.

Technical facilities and knowledge include the abilities and industry of technical employees, layout and design of building, equipment, apparatus and tools, design of product and instructions for manufacture, and other technical resources for effectiveness.

Utilization of facilities, knowledge, and organization comprises training of workers on all jobs and tasks, records of workers and machines, methods of purchasing, storeskeeping, planning production, scheduling, routing, dispatching, inspecting, and other activities having to do with the effectiveness of utilization.

Ferguson determined the relative values, or weights, of these three factors for metal-working plants. These are:

		Points
K (organization factor)	=	35
T (technical factor)	=	20
U (utilization factor)	=	45

Or,

$$35 + 20 + 45 = 100 \text{ points}$$

It is evident that the precise values for these factors are not definitely determinable because there are many elements to be taken into account under each of the three headings, and intangible influences enter which are not adapted to exact measurement. However, approximate values may be set up whose sum in the above equation would represent what is believed to be 100% performance, and the relative percentage efficiency of each factor can then be evaluated. The formula to use for over-all operating effectiveness would then be:

$$E = aK + bT + cU$$

where

E = Total or resulting effectiveness of management
a = % effectiveness of organization factor, K
b = % effectiveness of technical factor, T
c = % effectiveness of utilization factor, U

MANUFACTURING RATIOS: ROE.—Roe has developed a group of theoretical ratios for the principal factory operations (Trans. A.S. M.E., vol. 45). The extent of their adoption cannot be ascertained, but the utilization of the ratio method is fairly common. Roe's ratios are given in the accompanying tabulation.

Formulas for Manufacturing Ratios
(Joseph W. Roe)

Operation	Ratio
Purchasing	$\frac{M_1 + M_2 + M_3, \text{ etc.}}{C_1 + C_2 + C_3, \text{ etc.}}$

where M_1, M_2, etc., are the products of the monthly consumption of a selected basic material multiplied by the average market price for that material during that month, C_1, C_2, etc., are the actual costs of these materials as purchased.

Operation	Ratio
Production	
With respect to Plant, Equipment	$\frac{\frac{\text{Annual sales in dollars}}{\text{Plant investment in dollars}}}{\frac{\text{Total annual output of industry}}{\text{Total investment in industry}}}$
With respect to Materials	$\frac{\frac{\text{Annual sales in dollars}}{\text{Total annual purchase of materials}}}{\frac{\text{Total annual output of industry}}{\text{Value of raw materials used in industry per annum}}}$
With respect to Labor	$\frac{\frac{\text{Annual sales in dollars}}{\text{Total annual payroll in dollars}}}{\frac{\text{Total annual output of industry}}{\text{Total annual payroll of industry}}}$
Use of Equipment	$\frac{\text{Actual production machine hours}}{\text{Machine hours' capacity of plant}}$
Quality of Output	$\frac{\text{Goods produced which pass all inspections}}{\text{Total goods produced}}$
Promises of Shipment	$\frac{\text{Number of promises kept}}{\text{Number of promises made}}$
Labor Turnover	$\frac{\text{Turnover of plant under consideration}}{\text{Turnover of that trade and locality}}$

Radford (Mech. Eng., vol. 46) believes that the measurement of quality of output by Roe's ratios given above would be approximate only. If approximate figures are resorted to, they must be used with judgment, and if judgment is to be used in the analysis, it may well be used at the start. He therefore offers as a constructive substitute a critical examination of the following factors, numbered 1 to 3, believing that they will yield a more reliable check on the quality attainment of a given management. To Radford's three, a fourth has been added:

"1. Reputation for quality in the trade, to be checked by recent complaints from customers and by noting the standard and the degree of uniformity of current product.
2. Calculated money loss in spoilage and seconds (a figure which any adequate cost system should reveal), checked in physical form by the size of the scrap pile and its rate of increase, and by lists of defective goods sold at a loss; and corrected for current and unavoidable difficulties introduced by some temporary trouble with new product, poor material, unskilled labor, unsuitable machinery, etc.
3. Careful analysis in the factory of the adequacy of methods in use for insuring a continuous and positive control of quality. Does inspection provide a filter to protect the factory against an influx of poor material, and does it prevent the shipment of defective product? Are the standards properly set and furnished to the shops in usable form? Are the inspection reports a reasonably true measure of the quality situation in each product class? Is a reasonable proportion of the actual product being made in conformity with said standards?"
4. Inspection standards should be set from a careful analysis of the requirements to be met by the finished article as used by the consumer. Great losses are invited through failure to set this standard properly.

KILO MAN-HOUR METHOD: ALFORD-HANNUM.—Alford and Hannum (Trans. A.S.M.E., MAN-51-2) developed a group of factors based upon the man-hour. Reasons for selecting this base are that it is:

1. Measurable by an established unit.
2. Universal in use in industry.
3. Easy to handle in computation.
4. Influential in its effect on industrial operation.

As a matter of convenience they took 1,000 man-hours, the "kilo manhour" (kmh) as the unit of the system to yield quantities for combined units ranging in most cases from two to four significant figures and therefore of a kind easy to handle and memorize.

From this base unit, kmh., numerous factors of industrial operation can be developed. Most important are those below.

Factor	How Expressed
Costs:	
Fuel and electric energy	Dollars per kilo man-hour
Manufacturing cost	
Materials cost	
Overhead (burden) charges	
Prime cost	
Salaries	
Supervision	
Value added by manufacture	
Wages	

Factor	How Expressed
Fixed Capital Investment:	
Buildings	Investment in dollars per kilo man-hour, or Square feet of floor area per kilo man-hour
Land	Investment in dollars per kilo man-hour
Machinery	Investment in dollars per kilo man-hour
Industrial Accidents:	
Frequency	Number of lost-time accidents per 1,000 kilo man-hours
Severity	Number of working hours lost per kilo man-hour
Primary Power	Horsepower utilized per kilo man-hour
Productivity	Physical volume of product per kilo man-hour
Profit:	
Manufacturing	Dollars per kilo man-hour
Selling	Dollars per kilo man-hour
Net	Dollars per kilo man-hour
Selling Price	Dollars per kilo man-hour
Working Force Requirement	Total number of workers employed per kilo man-hour

It is self-evident that many of these combined factors can be separated into component elements for purpose of comparison and analysis.

MEASUREMENT OF TECHNOLOGICAL UNEMPLOYMENT.—The kmh. method has been applied to measurement of technological unemployment. Four groups of statistics are required:

1. Number of man-hours worked.
2. Average number of workers employed.
3. Total number of workers employed.
4. Quantity of product output.

Number of man-hours worked is total number of man-hours worked during each month, if taken on a monthly basis, by all workers engaged in plant operation and maintenance including straight overtime workers, if any. It should be given as actual hours worked, not payroll hours.

Average number of workers employed is number of workers engaged in plant operation and maintenance; that is, all skilled and unskilled laborers, such as mechanics, machine operatives, assemblers, engineers, firemen, watchmen, and the like, including pieceworkers actually employed in the producing operation of the establishment on the 15th day of each month or nearest representative day if taken on a monthly basis. This quantity is average number of workers required for plant operation and maintenance for each month, and not total number of workers on the payroll during the month.

Total number of workers employed is total number engaged in plant operation and maintenance actually on the payroll during each month

if taken on a monthly basis. This quantity includes the workers hired and fired during the month.

Quantity of product output is total quantity of product turned out during each month if taken on a monthly basis, expressed in such physical units as tons, pounds, gallons, barrels, bales, yards, square yards, cubic yards, feet, square feet, board-feet, cubic feet, kilowatt-hours, cases, pairs, dozens, numbers, and the like. When such nonstandardized units as tons, barrels, bales, cases, and the like are reported, the weight or capacity per unit should be specified; that is, number of gallons per barrel, number per case, number of pounds per bale, number of pounds per ton (long or short), and the like.

Units of Measurement for Employment.—From the four statistical quantities explained in the preceding paragraphs are derived seven units of measurement having to do with employment. These are:

1. Employment unit = Kilo man-hours worked
2. Productivity unit = Quantity of product output per kilo man-hour worked
3. Working force requirement = Total number of workers employed per kilo man-hour worked
4. Labor utilization unit = Average number of workers employed per unit of product
5. Labor utilization unit = Quantity of product output per worker
6. Labor time unit = Man-hours worked per worker
7. Time utilization unit = Man-hours worked per unit of product

Each of these units of measurement, or factors of employment, is a ratio computed on a standard-hour basis, by dividing one of the four statistical quantities given above by another. Computation of each is given in the following tabulation of "Units of Measurement for Factors in Industrial Operation." Significance of these seven units of measurement as given by the authors is as follows:

1. **Employment unit** indicates directly an increase or decrease in time employment and therefore is a quantitative measure of employment. It is believed to be the only correct measure of the trend of industrial employment.

2. **Productivity unit** is a measure of the rate of production, commonly designated as productivity, by indicating an improvement or recession in industrial effectiveness. That is, it is an indication of technological change.

3. **Working force requirement** is measure of labor stability (reciprocal of labor turnover) and indicates effectiveness of managerial skill in handling personnel. It represents the number of workers that were required during a month to produce 1,000 man-hours of work. It indicates that part of technological advance or recession which results in the effective or ineffective handling of workers.

4. **Labor utilization unit,** which is average number of workers employed divided by quantity of product output, measures saving or waste in human effort. The more workers required to produce a unit of output, the greater the waste in human effort; the fewer workers required to produce a unit of output, the greater the saving in human effort.

5. **Labor utilization unit,** which is quantity of product output divided by average number of workers employed, is the reciprocal of the preceding unit which is also the unit of labor utilization. In some instances this factor is more convenient to use than the one that precedes.

6. **Labor time unit** measures length of the work period and indicates, depending upon the scope of the data, (1) whether the length for such establishment fluctuates from period to period; (2) whether the length of any period for each establishment is longer or shorter than the average length of the same period for the particular industrial group; (3) whether the trend for each industry is an increase or decrease in the length of the work period on the basis of both intra-industry and inter-industry comparisons.

7. **Time utilization unit** is the reciprocal of the productivity unit and indicates an effective technological advance for it measures the saving of otherwise wasted time. Time is wasted when a greater number of man-hours is utilized to produce a unit of output; time is saved when a fewer number of man-hours is utilized to produce a unit of output. This unit indicates, further, the influence of time-saving equipment upon industrial development as a result of technological advance.

PURCHASING DEPARTMENT EFFICIENCY.—Measuring purchasing department efficiency serves a double purpose:

1. It permits the management to keep an actual check upon how well the purchasing department is doing its job.
2. It permits the purchasing agent to analyze and measure his own task and his relative performance.

Factors in purchasing efficiency are:

1. Proved savings.
   a. Proved savings on goods bought at prices under current market prices.
   b. Proved savings achieved by initiation of improved methods or substitution of better or lower-priced materials.
2. Expense of operating purchasing department.
3. Expense caused by purchasing department failures.
   a. Losses caused by purchasing goods at prices above the average market.
   b. Purchasing loss-and-error account.
   c. Cost of failure to have material on hand when needed.
   d. Losses from return of goods to vendors.

Of these factors 1 is a credit to the purchasing department's account; 2 and 3 are debit items. To establish purchasing efficiency there must be reports to management, substantiated by the proper authorities, indicating the department's standing on each of these factors.

A specimen and computation for purchasing department efficiency index, using assumed figures for a given period, is:

Total purchases for year..............................	$1,234,567.89
Net cost of purchasing (total debits − total credits).....	58,871.16
Purchasing inefficiency $= \frac{\text{Net cost of purchasing}}{\text{Total purchases}} =$	.0477
Taking theoretical standard of perfection as.............	100.00
Deduct percentage of purchasing inefficiency.............	4.77
	95.23

Purchasing department efficiency index = 95.23%

STOREROOM EFFECTIVENESS.—Where a perpetual inventory, or balance-of-stores record, is maintained with a physical check of each item against the record, either at stated periods, or when a new manufacturing requisition is made out, a measure is available of the effectiveness of storeroom operation. If a record is kept of all discrepancies—either over or under the inventory record—and these variations are extended into dollar value, this amount can be used to establish a percentage of variation to the total value of the inventory. A good record for this discrepancy would be less than ½%. In numerous cases it is as low as 1/10%.

PRODUCTION-CONTROL EFFECTIVENESS.—A measure of the effectiveness of production-control methods is afforded by comparing the number of orders promised for delivery on specified dates and those actually shipped on those dates. It is a fair assumption that when an order is shipped it is of the "required quantity" and "required quality." A good production-control record, when measured in this manner, would be about 95% for nonemergency conditions of operation.

MEASURING COST ACCOUNTING WORK.—As a measure of cost accounting and general accounting work, Cartmell (Mech. Eng., vol. 46) suggests establishing by judgment a quota of good points, say 1,000 points per month. Each failure or error, including failure to complete the work in the time set, would be evaluated in points according to its importance.

The formula for determining operating efficiency then is:

$$\text{Efficiency of cost and/or accounting department} = \frac{1{,}000 - \text{Number of points penalized for errors and failures}}{1{,}000}$$

No separation should be made between the cost department and the general accounting department when determining a method of evaluating efficiency, because their functions, methods, routines, and schedules are too closely related and interdependent; in fact, the two form one department in small organizations.

Standards can be, and are being, used for evaluating the accuracy of the accounting function. In each case, 100% accuracy would be the aim for each routine (payroll compilation, labor distribution, etc.) even though it is recognized beforehand that some errors will be made.

Reasonable checks for accuracy should be established for each routine, and penalties established of so many points for each error found in a final report or record.

Definite dates can be established for completing every routine of the accounting function, and **deviations from schedule dates** can be evaluated in penalty points similarly to the evaluating of errors. For instance, payrolls must always be ready at a certain time. In most plants employing less than 500 workers, job costs should be compiled in four working days after the completion of a manufacturing order; departmental overheads, etc., in five working days; and the profit and loss statement and balance sheet in eight working days. Special and unusual conditions may lengthen this period in some plants.

Plants of 1,500 workers usually require approximately one-third additional time, and some large organizations with scattered plants need even longer periods.

Units of Measurement for Factors in Industrial Operation

FACTOR	UNIT	COMPUTATION
Absenteeism	Days absent from work per period (week, month, or year)	
Accident fatality rate	Number of fatalities per 1,000,000 man-hours worked	$= \dfrac{\text{Number of fatalities}}{\dfrac{\text{Number of man-hours worked}}{1{,}000{,}000}}$
Accident frequency rate	Number of disabling injuries per 1,000,000 man-hours worked	$= \dfrac{\text{Number of disabling injuries}}{\dfrac{\text{Number of man-hours worked}}{1{,}000{,}000}}$
Accident permanent disability rate	Number of permanent disabilities per 1,000,000 man-hours worked	$= \dfrac{\text{Number of permanent disabilities}}{\dfrac{\text{Number of man-hours worked}}{1{,}000{,}000}}$
Accident severity rate	Number of days lost through disabling injuries per 1,000 man-hours worked	$= \dfrac{\text{Number of days lost through disabling injuries}}{\dfrac{\text{Number of man-hours worked}}{1{,}000}}$
Allowance for delays	Percentage of cycle time	$= \dfrac{\text{Time for necessary delays per cycle}}{\text{Net cycle time}}$
Average life of any class of equipment	Years	$= \dfrac{\text{Total years of service of units}}{\text{Number of units in the group}}$
Budget performance	Percentage actual performance of the estimated performance	$= \dfrac{\text{Actual performance} \times 100}{\text{Estimated performance}}$
Conveyor speed	Feet per minute	
Cost accounting efficiency (Cartmell)	Ratio of points assigned for good work to total number of points assigned	$= \dfrac{1{,}000 - \text{Number of points penalized for errors and failures}}{1{,}000}$
Cost decrease (Lichtner)	Savings per hour	$= \text{Original cost} \times \left(\dfrac{1 + \%\ \text{Production increase}}{100}\right) - \text{Proposed cost}$

Item	Unit	Formula
Cotton manufacturing, spindle activity	Number of active spindles. Total spindle hours. Hours per spindle in place	$= \dfrac{\text{Total spindle hours}}{\text{Number spindles in place}}$
	Percentage of capacity	$= \dfrac{\text{Total spindle hours} \times 100}{\text{Possible spindle hours in working period on single shift basis exclusive of holidays}}$
Cutting feed, machine tools	Inches per minute	
Cutting rate, machine tools	Cubic inches per minute	= Depth of cut in inches × Width of cut in inches × Feed in inches per minute
Cutting speed, machine tools	Feet per minute	
Departmental performance	Percentage of product produced to product scheduled	$= \dfrac{\text{Product produced} \times 100}{\text{Product scheduled}}$
Departmental performance (Sylvester)	Percentage man-hours worked (direct labor) to man-hours scheduled	$= \dfrac{\text{Man-hours worked} \times 100}{\text{Man-hours scheduled}}$
Dust in air in work places	Dust particles per cubic foot of air	
Elevator speed	Feet per minute	
Embodied labor	Number of workers	$W = \dfrac{CL}{E}$ Where C = Annual money cost of purchased materials, services and equipment L = Proportion of C paid to labor, expressed as a fraction E = Average annual earnings of workers producing items making up C.
Employment (kmh. system)	Kilo man-hours worked	$= \dfrac{\text{Number of man-hours worked}}{1{,}000}$
Employee service expense budget	Per capita charge, rate	$= \dfrac{\text{Employee-service expense cost}}{\text{Number of workers}}$
Equipment, value of item of (Rautenstrauch)	See "Output, unit cost of"	
Fatigue and variation in rhythm allowance	Percentage of handling time	

Units of Measurement for Factors in Industrial Operation (*Continued*)

FACTOR	UNIT	COMPUTATION
Finished goods turnover	Ratio of cost of goods sold to average inventory of finished products at cost	$= \frac{\text{Cost of goods sold}}{\text{Average inventory of finished products at cost}}$
Floor space	Square feet	
Humidity of air in work places	Relative humidity in per cent	$= \frac{\text{Moisture contained in the air} \times 100}{\text{Moisture air is capable of holding at its temperature}}$
Illness	Days lost from work due to illness per period (week, month, or year)	
Illumination	Foot-candle = 1 lumen per square foot = illumination received by a surface 1 square foot in area, every point of which is distant 1 foot from a source of 1 candlepower	
Industrial relations expense budget	Per capita charge, rate	$= \frac{\text{Industrial relations expense}}{\text{Number of workers}}$
Inspection rating for defects	See "Quality of product"	
Inspection accuracy	Percentage from overinspection	P = Inspector accuracy $P \text{ (in \%)} = \frac{d_1 - d_3}{d_1 - d_3 + d_2}(100)$ Where d_1 = Number of defects reported by inspector d_2 = Number of pieces passed by inspector subsequently found defective d_3 = Number of pieces reported defective by inspector subsequently found satisfactory
Inventory turnover	Ratio of cost of goods sold to average inventory	$= \frac{\text{Cost of goods sold}}{\text{Average inventory at cost}}$
Labor budget	Ratio of actual cost of labor to actual cost of production	$= \frac{\text{Actual cost of labor}}{\text{Actual cost of production}}$

Term	Definition	Formula
Labor budget	Ratio of estimated cost of labor to estimated cost of production	$= \dfrac{\text{Estimated cost of labor}}{\text{Estimated cost of production}}$
	Percentage actual labor cost of estimated labor cost	$= \dfrac{\text{Actual labor cost} \times 100}{\text{Estimated labor cost}}$
Labor efficiency	Percentage standard times to actual times	$= \dfrac{\text{Standard times} \times 100}{\text{Actual times}}$
Labor, indirect	Percentage indirect labor to direct labor	$= \dfrac{\text{Indirect labor in man-hours} \times 100}{\text{Direct labor in man-hours}}$
Labor-saving ratio	Ratio of reduction of labor requirements	$S = 1 - \left(\frac{W}{F} \times \frac{1}{P}\right)$ Where W = Number of workers required under new method F = Number of workers required under old method P = Ratio of total outputs, new method to old method
Labor time	Man-hours worked per worker	$= \dfrac{\text{Number of man-hours worked}}{\text{Number of workers}}$
Labor turnover	Ratio of separations to average working force per period, usually month or year	$= \dfrac{\text{Number of separations}}{\text{Average number in working force}}$
Labor turnover—discharges	Ratio per 100 employees	$= \dfrac{\text{Number of discharges}}{\frac{\text{Number on payroll}}{100}}$
Labor turnover—lay-offs	Ratio per 100 employees	$= \dfrac{\text{Number of lay-offs}}{\frac{\text{Number on payroll}}{100}}$
Labor turnover—quits	Ratio per 100 employees	$= \dfrac{\text{Number of quits}}{\frac{\text{Number on payroll}}{100}}$
Labor turnover—separations	Number of separations	= Sum of discharges + Lay-offs + Quits

Units of Measurement for Factors in Industrial Operation *(Continued)*

FACTOR	UNIT	COMPUTATION
Labor utilization	Physical volume of product output per worker	$= \frac{\text{Physical volume of product output}}{\text{Number of workers}}$
	Average number of workers employed per unit of product output	$= \frac{\text{Average number of workers employed}}{\text{Product output}}$
Machine efficiency	Percentage of theoretical output	$= \frac{\text{Quantity of production} \times 100}{\text{Theoretical total production capacity}}$
Machine idleness	Hours or days per period (day, week, month, or year)	
Machine requirements	Number of machines	$N =$ Number of machines required $N = \left(\frac{T}{60}\right)\left(\frac{P}{HC}\right)$ Where T = Standard time for the operation in minutes P = Production required per day of standard number of hours H = Standard number of hours per day C = Factor of use of equipment taken as .85
Machine speed	Revolutions per minute	
Man idleness	Hours or days per period (day, week, month, or year)	
Manufacturing expense budget	Ratio estimated manufacturing expense to estimated cost of production	$= \frac{\text{Estimated manufacturing expense}}{\text{Estimated cost of production}}$
	Percentage actual cost of manufacturing expense to estimated cost of manufacturing expense	$= \frac{\text{Actual cost of manufacturing expense} \times 100}{\text{Estimated cost of manufacturing expense}}$
	Ratio actual cost of manufacturing expense to actual cost of production	$= \frac{\text{Actual cost of manufacturing expense}}{\text{Actual cost of production}}$
Materials budget	Percentage actual materials to estimated materials inventory	$= \frac{\text{Actual materials inventory} \times 100}{\text{Estimated materials inventory}}$

Materials yield	Percentage yield of materials	$= \frac{\text{Materials in the product} \times 100}{\text{Materials used in producing the product}}$
Motion study observations (Gilbreth)	Readings taken to one-thousandth of a minute = .001 min. "Wink" or one two-thousandth of a minute = .0005 min., is also used.	
Noise	Decibel	
Over-all efficiency of industrial plant (De Leeuw)	Rate of total efficiency to efficiency of purpose	$E_1 = \frac{E_t}{E_p}$ E_1 = Efficiency of plant E_p = Efficiency of purpose E_t = Total efficiency
Output, unit cost of (Rautenstrauch)	Unit cost in dollars	t = Cost of unit of output in dollars $= \frac{P(a+b+c+d)}{N} + \frac{l+s}{n}$ Where P = Cost to procure equipment, in dollars a = Interest rate, % b = Tax rate, % c = Insurance rate, % d = Depreciation rate, % N = Estimated annual output, number/yr. l = Labor cost/hr of operation s = Service cost/hr. of operation n = Estimated hourly output, number/hr.
Over-all effectiveness of individual plant (Ferguson)	Percentage of effectiveness	E = Effectiveness of operation $= aK + bT + cU$ Where a = % effectiveness of organization b = % effectiveness of technical facilities c = % effectiveness of utilization of all facilities K = Factor of organization for a particular industry T = Factor of technical facilities for a particular industry U = Factor of utilization for a particular industry $K + T + U = 100$ points

Units of Measurement for Factors in Industrial Operation (*Continued*)

FACTOR	UNIT	COMPUTATION
Overhead rate on direct labor hours	Amount of normal overhead per direct labor hour for a department, machine class, or production center	$= \frac{\text{Normal annual overhead for department in dollars}}{\text{Normal annual number of direct labor hours worked in the department}}$
		$= \frac{\text{Normal annual overhead for machine class in dollars}}{\text{Normal annual number of direct labor hours worked on machines in the class}}$
		$= \frac{\text{Normal annual overhead for the production center in dollars}}{\text{Normal annual number of direct labor hours worked in the production center}}$
Overhead rate on direct labor cost	Amount of normal annual overhead per dollar of direct labor cost for a department, or machine class, or production center	$= \frac{\text{Normal annual overhead for the department in dollars}}{\text{Normal annual labor cost for the department in dollars}}$
		$= \frac{\text{Normal annual overhead for the machine class in dollars}}{\text{Normal annual labor cost for the machine class in dollars}}$
		$= \frac{\text{Normal annual overhead for the production center in dollars}}{\text{Normal annual labor cost for the production center in dollars}}$
Overhead rate on machine hours	Amount of normal annual overhead per machine hour for a department, machine class, or production center	$= \frac{\text{Normal annual overhead for the department in dollars}}{\text{Normal annual number of machine hours worked in the department}}$
		$= \frac{\text{Normal annual overhead for the machine class in dollars}}{\text{Normal annual number of machine hours worked by machines in the class}}$
		$= \frac{\text{Normal annual overhead for the production center in dollars}}{\text{Normal annual number of machine hours worked in the production center}}$

Overhead rate on direct materials	Amount of normal annual overhead per cent. or per dollar, of direct materials for a department or machine class, or production center	$= \dfrac{\text{Normal annual (dept.) overhead in dollars}}{\text{Normal annual amount of materials for the department in physical units}}$
		$= \dfrac{\text{Normal annual departmental overhead in dollars}}{\text{Normal annual cost of materials for the department in dollars}}$
		$= \dfrac{\text{Normal annual overhead for the machine class in dollars}}{\text{Normal annual amount of materials for the machine class in physical units}}$
		$= \dfrac{\text{Normal annual overhead for the machine class in dollars}}{\text{Normal annual cost of materials for the machine class in dollars}}$
		$= \dfrac{\text{Normal annual overhead for the production center in dollars}}{\text{Normal annual amount of materials for the production center in physical units}}$
		$= \dfrac{\text{Normal annual overhead for the production center in dollars}}{\text{Normal annual cost of materials for the production center in dollars}}$
Overhead rate on product	Amount of normal annual overhead per unit of physical product for a department, or machine class, or production center	$= \dfrac{\text{Normal annual overhead for the department in dollars}}{\text{Normal annual output of product of the department in physical units}}$
		$= \dfrac{\text{Normal annual overhead for the machine class in dollars}}{\text{Normal annual output of product for the machine class in physical units}}$
		$= \dfrac{\text{Normal annual overhead for the production center in dollars}}{\text{Normal annual output of product for the production center in physical units}}$

Units of Measurement for Factors in Industrial Operation (*Continued*)

FACTOR	UNIT	COMPUTATION
Passed work	Percentage of work passed inspection	$= \dfrac{\text{Number of pieces passed} \times 100}{\text{Total number of pieces}}$
Permanent disability frequency rate	Number of permanent disabilities per 1,000,000 man-hours worked	$= \dfrac{\text{Number of permanent disabilities}}{\dfrac{\text{Number of man-hours worked}}{1{,}000{,}000}}$
Plant capacity (kmh. system)	Kmh. per year	$= \dfrac{\text{Number of man-hours capable of being worked per year}}{1{,}000}$
Power for machines	Horsepower, watts	
Primary power	Horsepower, kilowatts	
Primary power (kmh. system)	Horsepower utilized per kilo man-hour	$= \dfrac{\text{Number of horsepower utilized}}{\dfrac{\text{Number of man-hours worked}}{1{,}000}}$
Probable life of physical property	Years	= Age (in years) + Life expectancy (in years) at that age
Production budget	Percentage actual production to estimated production	$= \dfrac{\text{Actual production} \times 100}{\text{Estimated production}}$
Productivity	Physical volume per man-hour	$= \dfrac{\text{Physical volume}}{\text{Number of man-hours}}$
	Physical volume per man-day	$= \dfrac{\text{Physical volume}}{\text{Number of man-days}}$
	Physical volume per machine-hour	$= \dfrac{\text{Physical volume}}{\text{Number of machine-hours}}$
Productivity (kmh. system)	Physical volume of production output per kilo man-hour	$= \dfrac{\text{Physical volume of production output}}{\dfrac{\text{Number of man-hours worked}}{1{,}000}}$
Purchase budget	Percentage actual purchases to estimated purchases	$= \dfrac{\text{Actual purchase} \times 100}{\text{Estimated purchases}}$

Purchasing efficiency	Percentage	$= 100 - 100 \left\{ \dfrac{\text{Total cost of operating purchasing department} - \text{Proved savings (dollars)}}{\text{Total volume of purchases (dollars)}} \right\}$
Quality of product (relative)	Index number	$I = \dfrac{\text{Current demerits per unit}}{\text{Base period demerits per unit}}$ $= \dfrac{A + B + C + D}{E}$ Where A = Number of Class A (very serious) defects × 100 B = Number of Class B (serious) defects × 60 C = Number of Class C (moderately serious) defects × 25 D = Number of Class D (not serious) defects × 5 E = Average base period defects determined for an immediately preceding period, as 5 years
Raw materials inventory turnover	Ratio of amount of raw materials put into process to average raw materials inventory	$= \dfrac{\text{Amount of raw materials put in process}}{\text{Average raw materials inventory}}$
Room volume	Cubic feet	
Shipping promises broken	Percentage of promises broken to total	$= \dfrac{\text{Number of promises broken} \times 100}{\text{Total number of promises made}}$
Shipping promises kept	Percentage of promises kept to total	$= \dfrac{\text{Number of promises kept} \times 100}{\text{Total number of promises made}}$
Span of Control (Graicunas)	Number of relationships	$F = A + B + C$ N = Number of subordinates A = Number of direct, single relationships $A = N$ B = Number of cross relationships $B = \dfrac{N}{2}(N - 1)$ C = Number of direct group relationships $C = 2^N - (N + 1)$
	Percentage of spoiled work	$= \dfrac{\text{Number of spoiled pieces} \times 100}{\text{Total number of pieces}}$

Units of Measurement for Factors in Industrial Operation *(Continued)*

FACTOR	UNIT	COMPUTATION
Standard time	Minutes and hundredths of a minute	S = Standard time $S = T + T(D + N + F)$ Where T = Cycle time for the elements D = % allowance for delays N = % allowance for personal needs F = % allowance for fatigue
Standard time (Bedaux system)	"B" or work assigned to 1/60 of an hour	
Standard time (Manit system)	"Manit" or standard man-minute of work	
Standard time (Point system)	"Point" or work assigned to 1/60 of an hour	
Standard time performance	Percentage of time taken to time allowed	$= \frac{\text{Time taken} \times 100}{\text{Time allowed}}$
Stores issued	Quantity easily handled or normally issued at one time	
	Quantity stocked in terms of normal stock per period	
Supplies turnover	Ratio supplies expense to average investment in supplies stock	$= \frac{\text{Supplies expense}}{\text{Average investment in supplies stocks}}$
Temperature of work places	Degrees Fahrenheit	
Time-study observations	One-hundredth of a minute = .01 min.	
Time utilization	Man-hours worked per unit of product output	$= \frac{\text{Man-hours worked}}{\text{Product output}}$
Wage earnings	Dollars per day or week	
Wage increase (Lichtner)	Percentage wage increase to original wages	$= \frac{(\text{Proposed wages} - \text{Original wages})\ 100}{\text{Original wages}}$
Wage rate	Cents per hour	
	Dollars per day or week	
Working force requirement (kmh. system)	Total number of workers employed per kilo man-hour worked, rate	$= \frac{\text{Total number of workers}}{\frac{\text{Number of man-hours worked}}{1{,}000}}$
Work-in-process turnover	Ratio cost of finished product to average cost of work-in-process inventory	$= \frac{\text{Cost of finished product}}{\text{Average cost of work-in-process inventory}}$

SECTION 23

MANUFACTURING COSTS

CONTENTS

PAGE

Overhead and Product Cost

Normal Burden

Specific Order Cost Systems

Continuous Process Cost Systems

PAGE

Joint and Byproduct Costs

Setting Standard Costs

Cost Control and Cost Variations

Cost Reports

SECTION 23

MANUFACTURING COSTS

Methods of Costing

PRODUCTION COST DEFINED.—Production cost represents the sum total of expenditures incurred in converting raw material into a finished product. These include, in addition to the material cost, all direct labor and all plant overhead resulting from facilities used in production. Such costs may be computed in a variety of ways:

1. By conventional financial accounting methods.
2. By use of cost accounting technique.
3. By various estimating procedures.

FINANCIAL ACCOUNTING DEFINED.—Financial accounting is concerned only with over-all results. It arrives at a cost of production by the use of the formula shown in Fig. 1.

There are two drawbacks to this method of accounting:

1. Necessity for taking physical inventory each time statements are prepared.
2. Lack of internal data.

Even where **perpetual inventories** are in use as part of a financial accounting system, the resulting information still falls short of meeting the production man's requirements. This is because financial accounting is concerned with recording relationships to outsiders. It shows the results of values added through manufacture, but cost accounting traces the added value through each stage of production. The accounts are so organized that they show the internal flow of the product, step by step, from the raw material stage to its final emergence as a finished product.

COST ACCOUNTING DEFINED.—Cost accounting, operating as an extension of the principles of accounting and of double-entry bookkeeping, provides procedures for the recording and analysis of expenditures of a business in the following ways:

1. By plant divisions, such as manufacturing, distribution, administration.
2. By functional activities within each, such as cost centers and departments.
3. By cost elements, such as material, labor, and expenses.
4. By products and component parts for each stage of manufacture.

Usually the resulting costs are reduced to a unit basis.

STATEMENT OF PRODUCTION COST
January 1, 19—, to January 31, 19—

Direct Materials:		
Stores Inventory, January 1		$60,000.00
Purchases of Stores	$29,777.00	
Reclaimed Materials and Scrap	14.00	
Total Charges to Stores during January		29,791.00
Total Stores Available for Use		$89,791.00
Stores Inventory, January 31		56,000.00
Total Stores Issued		$33,791.00
Indirect Materials Used		3,791.00
Cost of Direct Materials Used		$30,000.00
Direct Labor		18,000.00
Factory Overhead Expenses:		
Fuel	$ 775 99	
Spoilage	136.00	
Heat	80.00	
Light	186.00	
Power	485.00	
Water	24 00	
Compensation Insurance	133 51	
Auto Repairs and Supplies	45.00	
Indirect Materials and Supplies	3,791.00	
Indirect Factory Wages and Salaries	8,702.00	
Medical Fees	100.00	
Machine Royalty Rentals	4,600.00	
Patents Amortization	170.00	
Depreciation of Building and Equipment	2,066.00	
Insurance on Building and Equipment	466.00	
Taxes on Building and Equipment	489 50	
Total Factory Overhead Expenses		22,250.00
Production Charges Originating during January		$70,250.00
Defective Work Credit		150 00
Net Production Charges		$70,100 00
Work-in-Process Inventory, January 1		6,000.00
Total Net Production Charges		$76,100.00
Work-in-Process Inventory, January 31		8,100 00
Cost of Production for January		$68,000.00

FIG. 1. Cost of Production Schedule or Manufacturing Statement

The ultimate aim of the entire procedure is to use cost information:

1. To control expenditures by elimination of waste.
2. To price products.
3. To provide a basis for operating policies.

Cost Records and Accounts

COST CONTROL ACCOUNTS.—Cost transactions are recorded through a system of cost controlling accounts which may be kept in the general ledger or segregated in a factory ledger. Cost control accounts kept in a general or factory ledger are defined by Van Sickle (Cost Ac-

counting) as "accounts in which are recorded the transactions that pertain to the production and marketing functions of a business enterprise."

Below are shown the important cost controls and their respective subsidiary ledgers:

Control Account	Subsidiary Ledger
1. Stores	1. Balance-of-Stores Ledger
2. Work in Process	2. Job Order Cost Sheets or Process Ledger
3. Finished Parts	3. Finished Parts Ledger
4. Finished Goods	4. Finished Goods Ledger
5. Actual Manufacturing Expense	5. a. Primary Expense Ledger b. Departmental Expense Ledger or Expense Distribution Sheet

For convenience Work in Process is often subdivided by opening separate accounts for:

1. Cost elements, i.e., material, labor, and overhead.
2. Each department or cost center.

These accounts may be kept in the general ledger or in a **factory ledger.**

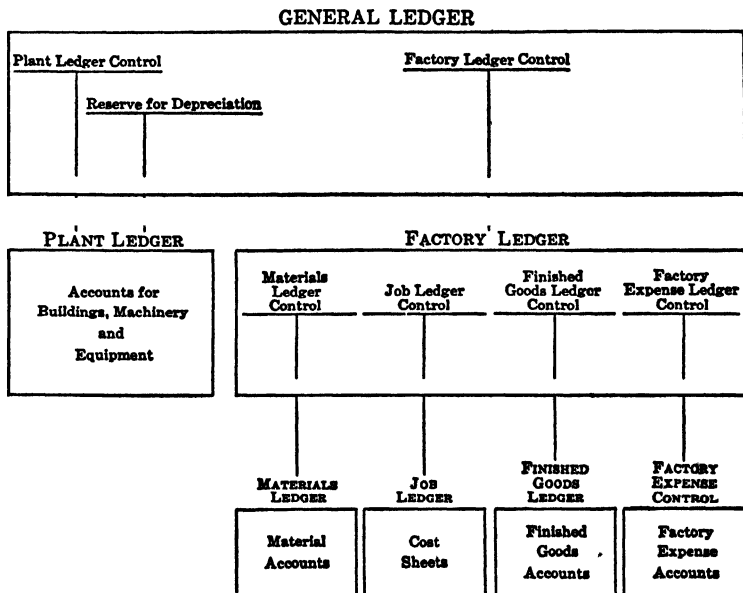
The relationship between the general ledger and the factory ledger is illustrated by Gillespie (Introductory Cost Accounting), Fig. 2. Note

GENERAL LEDGER

FIG. 2. Relationship of General Ledger to Factory Ledger

that the general ledger, and in this case the plant ledger which contains the building and equipment accounts, are kept at the general office. The other ledgers are kept at the factory office.

Cost Classifications

CAPITAL AND REVENUE EXPENDITURES.—Expenditures which add to the life of fixed or capital assets or which result in increased capacity or efficiency are called capital charges. Other expenditures necessary to maintain fixed assets in efficient working order, or incurred in the earning of revenue, are revenue charges. In general, expenditures connected with fixed assets may be classified under the following headings:

1. Additions and extensions.
2. Improvements and betterments.
3. Replacements.
4. Repairs and maintenance.

Additions and extensions involve an increase of available capacity and can properly be capitalized. They are similar to original expenditure in that capacity and facilities for use in the future are provided. **Improvements and betterments** involve alteration and modernization of existing buildings, equipment, machines, and other assets.

Betterments may or may not be accompanied by **replacements.** The addition of an electric motor to a machine formerly operated by hand is a betterment, probably without any important replacement of parts of the old machine. On the other hand, replacement of a 2-ton truck body by a 3-ton body is both a replacement and a betterment. In either case, betterment to the extent that the productive capacity of the asset was increased, is properly capitalized. In the second case, in addition, the asset account must be relieved of the cost of the portion of the asset replaced.

Maintenance and repair costs are revenue expenditures. They are costs of maintaining the plant in efficient working condition without increasing the productive capacity or appreciably extending the life of assets beyond the span contemplated in setting depreciation rates. Hence, they represent revenue charges.

DIVISIONAL COST CLASSIFICATIONS.—Divisional costs represent the major functions of industrial companies. Hence, they are also known as functional costs. Current costs are first arranged according to functional divisions of a business which usually are:

1. Production, i.e., manufacturing.
2. Distribution.
3. Administration.
4. Finance.

CLASSIFICATION OF MANUFACTURING COSTS.—The Joint Committee on Management Terminology has defined total manufacturing cost as follows:

> Costs to cover the cost of direct material, direct labor, and factory overhead; that is, the cost of goods ready for sale and shipment.

These costs must be so arranged and classified that computation on various bases becomes possible. Note that a classification suitable for one kind of information is not necessarily good for another. Once a body of costs has been recognized as production costs, the analysis of these costs by detailed classifications and the combining of the details to get unit costs of products and activities are practical matters of finding the basis of classification and methods of accumulation which give the most accurate unit costs and most useful cost control information consistent with clerical economy.

In the process of classifying costs, the accountant makes use of both analysis and synthesis:

1. Breakdown of the stream of costs into its individual components, each labeled in such a way as to permit ready accumulation.
2. Accumulation of these costs to provide data desired in the form of unit product costs and significant figures for cost control.

In the analysis phase of this process, four major bases of classification have been found particularly useful:

1. By nature of item or service acquired.
2. By costing unit.
3. By department, process, operation, or cost center.
4. By behavior, i.e., tendency to vary with rate of activity.

Classification by Nature of Expenditure.—In the process of analysis, the accountant first develops a list of accounts to indicate the nature of each item or service acquired. This may be simple or complex depending on the needs of each case. In one company there may be only one account for insurance, while in another company accounts may be provided for fire insurance, use and occupancy insurance, workmen's compensation insurance, etc. These accounts are known as primary charges.

Allied to this type of analysis is **classification by cost elements;** namely, material, labor, and expense. Each of these may be further subdivided. The Cordage Institute has suggested that for operating or direct departments the following breakdown of **factory overhead** be observed:

1. Supervision, oilers and clerks.
2. Truckers.
3. Sweepers and cleaners.
4. Weighers, elevator men.
5. Supplies.
6. Taxes.
7. Insurance—employees' liability.
8. Insurance—fire, etc.
9. Depreciation.

In addition, a separate classification of costs was suggested for each auxiliary or service department.

Costing Units.—Costing units or cost units are the factors in terms of which costs are expressed. Coal is measured by the ton, gasoline by the gallon, cloth by the yard, paper by the pound, lumber by the foot, and castings by the pound or hundredweight. As distinguished from bulk products, articles such as machines, shoes, pencils, furniture, and automobiles are measured by the unit of one or some multiple of one, which includes dozen and gross. With special jobs the unit is the job itself. These are the bases or units of cost of finished products.

A classification by costing units is provided in order that costs once classified may later be assembled to provide the cost of individual units of products, groups of units (job or process costs), or classes of units (class costs).

Cost Centers.—Most organizations are divided into departments for administrative purposes. For cost purposes these divisions are known as cost centers. Cost centers are established to charge direct costs, such as materials and direct labor, and to distribute burden.

The basis for setting up a cost center is a grouping of machines, methods, processes, operations, and the like, so as to segregate work activities having a common interest. Cost centers are of two types:

1. Producing or direct cost centers.
2. Service departments or centers.

The former represent departments engaged in processing the product. Service or auxiliary departments represent centers of nonproductive activities, such as power, storeroom, first aid, factory office, etc. An **expense burden center** is one set up (sometimes only on paper) to group items of expense in connection with a particular activity, which, of itself, is not a productive activity.

A plant should be divided into as many burden centers, productive and expense, as are needed to determine, collect, and distribute the overhead expense and apply it to the product.

Relation of Expenses to Departments.—For cost control purposes a distinction must be made between those costs which are a direct charge against a department and those which are indirect. When **primary manufacturing expenses** are being distributed to departments, they constitute direct charges to the indicated departments. But when the service department totals are redistributed to the other departments, the items which were direct charges to the service departments become indirect charges when viewed from the standpoint of the producing department to which the redistributions are carried.

Cost control is preferably based on **control at the source**; accordingly, a department foreman is held responsible only for those costs which are direct with respect to his department. Any indirect costs which are charged to his department through apportionment or proration are considered the responsibility of the foreman of the service department to which they were originally charged as direct costs. Thus, the cost of fuel for providing steam is an indirect cost from the viewpoint of products and jobs and of productive departments which use steam; but for the power plant, which is a service department, it is a direct cost.

Expense Behavior.—The relation of costs to changes in the volume of production or rate of activity is conditioned on the behavior of different cost elements. For control purposes, costs are classified as fixed, variable and semi-variable. This classification is essential in determining allowable costs for cost control purposes, and also in setting rates for the application of overhead.

Fixed costs do not vary in total amount with changes in the rate of production. Depreciation, insurance, and taxes are normally fixed costs. **Variable costs** tend to vary directly in total amount with variations in the rate of production. Workmen's compensation insurance and royal-

ties based on volume of production are of this type. Doubling the rate of production normally results in doubling the cost.

In addition, there are **semi-variable costs** which vary in total amount with variations in volume of production but not at the same rate. The cost of repairs and maintenance is usually considered semi-variable; a 50% increase in production may produce only a 30% increase in maintenance costs. Semi-variable items are really combinations of fixed and variable items, and through careful study it is possible to separate them and determine separately the amount of fixed cost and the rate of variation of variable element.

SYMBOLS AND CODES.—Symbols are the shorthand of classification. By use of symbols and codes, relationships may be indicated in an orderly way and lengthy descriptions reduced to simple form. Today in industry it is usual to develop sets of symbols, called codes, for a variety of data subject to classification. Cost accountants need to be familiar with many codes in order to classify properly:

1. Material, parts, and finished goods.
2. Labor operations.
3. Expenses
4. Jobs and departments.
5. Tools.
6. Fixed property.

Numerical Codes.—The simplest type of code is that obtained by assigning to items to be coded numbers from 1 up. Actually there are three kinds of numerical codes:

1. Sequence codes.
2. Block codes.
3. Group classification, or decimal codes.

Sequence codes are useful only when there is no need for subdivision by groups. Items to be coded should be arranged in some logical order before numbers are assigned. Since numbers are assigned in sequence, additions can be made only at the end of the classification by adding additional numbers. In accounting, sequence codes are commonly used in connection with jobs, requisitions, and other papers which are numbered in sequential order according to date of issuance.

To provide for grouping of data, **block codes** are often used. Thus, numbers from 0 to 9 might be set aside for asset accounts, 10 to 19 for liability accounts, etc. Limited expansion is provided under this method by reserving certain numbers for future use. Note that under the block code method, the number used signifies the group to which the item belongs as well as the specific item. Thus, number 11 might signify that the account was a liability account and also that it was a specific account, Notes Payable. Normally there is no provision for subdivision in a block code.

Probably the method of coding most commonly used in accounting is that providing for **group classifications** by having major and minor classifications represented by succeeding digits of a number. This plan allows for indefinite subdivision. The first digit in a code number represents the major classification, the second digit the secondary classification, and subsequent numbers finer subdivisions. Normally it is best

to decide in advance the degree of subdivision desired and express all code numbers by the same number of digits. Thus a code such as

1000—Assets
1100—Current assets
1110—Cash
1111—Petty Cash

requires four digits. If other parts of the code require further subdivision, it is desirable to add another digit to above numbers in order that all code numbers may have the same number of digits and the position of each digit from either left or right may have the same significance.

Decimal codes are particularly useful where it is desired to combine two fairly extensive classifications, as, for example, departments and expense accounts or a functional and a primary classification of expenses. Thus in the rubber industry's Uniform Accounting Manual, the figure 86 is assigned to Administration, 867 to the Controller's Division, 8675 to the general accounting division of the Controller's Division, and 86752 to the accounts payable department in the general accounting division. Code numbers following the decimal point are then used to indicate **primary expense** accounts. Thus, code 86752.101 would serve to designate salaries in the accounts payable department, and code 86752.193 stationery and office supplies for that department.

Letter Codes.—In addition to numerical codes, letters may be used, alone or in combination with figures to provide code designations. They may be assigned in alphabetical order or according to the sound of the name of the individual item being classified. Symbols of this latter type, designed to assist the memory, are called **mnemonic symbols.** Thus, in a classification of accounts, the letter "A" might be assigned to Assets, "L" to Liabilities, "X" to Expenses, etc. A second letter may be used to indicate subsidiary classification; for example, "AC" might indicate Current Assets, and "AF" Fixed Assets. Mnemonic symbols are used more commonly by engineers than accountants, and are quite often used in classifying materials.

The Cost Department

INFORMATION COMPILED BY COST DEPARTMENT.— The principal types of information collected by the cost department and its subdivisions are:

1. Cost elements (material, labor, and overhead) entering into costs of manufactured products.
2. Overhead or expense of operating each department of the business.
3. Analyses of causes as to why departments do not operate within their budgets and do not manufacture as economically as they should.
4. Operation of cost controlling accounts and all subsidiary and allied records connected therewith. These include perpetual inventories for raw material, finished parts, finished goods; primary expense ledgers, expense distribution sheets, job order cost sheets or process ledgers, etc.
5. Timekeeping data, where no separate department exists to handle this function.
6. Compilation of payrolls.
7. Preparation of reports and statements.

INFORMATION COMPILED BY GENERAL ACCOUNTING DEPARTMENT.—This department coordinates all accounting work and data as indicated in the following list of its most important duties:

1. The handling of all **detailed accounting papers** not passing through or recorded by the cost department, such as purchase invoices, sales invoices, general journal vouchers, cash receipts and disbursements, etc. The cost department receives memoranda of all such transactions affecting the cost of production and the expenses of operating the various departments of the business. Detailed accounting papers handled by the cost department are summarized by it and the summaries, frequently in journal entry form, are passed to the general accounting department for entry in the appropriate books of account.

2. The maintenance of the **controlling books of account** such as the general ledger and the accounts receivable and other ledgers, and of the

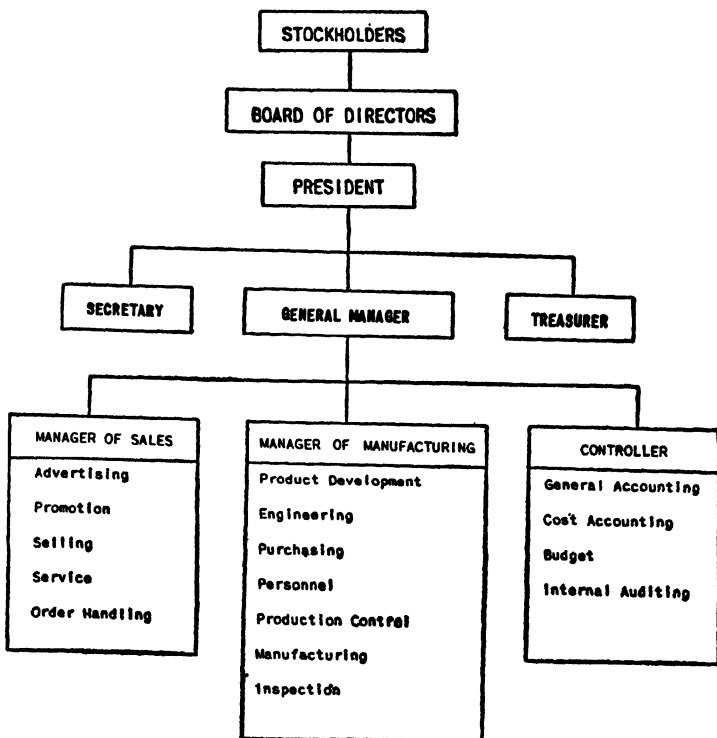



FIG. 3. Place of Controller in General Organization Plan of a Manufacturing Company

books of original entry such as the vouchers payable register, general journal, etc. The detailed stock records are likely to be maintained in other departments, but are nevertheless a part of the books of account and under functional accounting control. The various accounting papers mentioned in the preceding paragraph and the summaries of cost and expense factors prepared by the cost department are recorded in these books of account.

3. The **plant asset records.** Depreciation charges on machinery and equipment are accumulated from these records and reported to the cost department, and the latter in turn reports data for repairs, additions and disposals originating in the factory cost accounting records.

4. The preparation of **balance sheets** and **profit and loss statements.** Data supplied by the cost department are vital to preparation of these statements, e.g., cost of sales, inventory transactions, etc.

5. The compilation of sales and other **control statistics.** Costs of products sold and many data for these and other statistical analyses originate in the cost department.

6. The compilation of **tax statements.** Tax and other government statements require data to be prepared in certain formats and the amount of taxes paid depends, in part, upon the proper treatment of expenses in accordance with the law. The accounting department must observe those regulations in their day-to-day work.

The above definitely indicates the close relationship between general and cost accounting; neither activity can carry on its work without the closest cooperation of the other.

RELATION OF COST DEPARTMENT TO CONTROLLER.—Fig. 3 sets forth the place of the controller in the general organization plan of a manufacturing company. It also shows the organization of the departments over which he exercises jurisdiction. Note particularly that both the general and the cost accounting departments are represented as subdivisions of the controller's function.

ORGANIZATION OF COST DEPARTMENT.—The cost department's organization varies with the size of the business. A typical department is subdivided into the following sections:

1. Timekeeping.
2. Payrolls.
3. Labor Costs.
4. Material Accounting.
5. Overhead Accounting.
6. Cost and Expense Statements and Reports.

Chief Cost Accountant.—An executive in charge of a cost department is common to manufacturing companies, and while his official title may vary as between cost accountant, factory accountant, works accountant, and the like, his duties are more or less uniform. The chief cost accountant's duties include:

1. Supervision and coordination of all details in the collection of cost figures.
2. Presentation of cost and expense information developed in the cost department.
3. Study of the cost accounting plan and the resultant reports, to the end that they may become of increasing value in assisting the oper-

ating executives to manage and control their departments more effectively.

4. Contacting the executives of other departments, determining the needs and desires of these executives, and formulating plans for dissemination of cost data.

Cost Supervisors and Clerks.—Upon the cost clerks' shoulders rests the responsibility for examining and collating the many details of cost and expense information which are passing daily from factory and other departments to the cost department. One duty of the cost clerks is to post or distribute information regarding the consumption or use of materials. Labor charges likewise must be allocated to their respective jobs, operations, processes, departments, or expense classifications. Superimposed upon material and labor charges, burden must be distributed on some predetermined basis. Finally these amounts must be accumulated for reporting to management and for recording in the books of account.

Material Costs and Inventories

DETERMINING PURCHASE COST.—All costs incurred in getting raw materials and supplies into the plant up to the point of use are reflected as inventory cost on the stores cards. These costs include invoice price, purchasing department expense, transportation charges, receiving, storing, and handling expenses. Where possible, these costs are directly charged to the specific material involved; otherwise they are prorated and applied to the product in the form of predetermined material handling rates, either on a tonnage, or value, or some other convenient basis.

STORES ISSUES.—Materials are issued from the storeroom on the basis of stores requisitions or bills of materials. Stores requisitions are posted to the stores ledger as to quantities, and after being priced are ready to be charged to specific jobs or processes.

Stores Ledger.—The stores ledger is a perpetual inventory record and consists of ledger cards or sheets showing quantities received, issued, and on hand; also quantities ordered, reserved, and available, and finally a unit cost column. Total cost columns are, as a rule, unnecessary. So far as possible the entire stock record is kept in quantities only. Translation into dollar amounts takes place at inventory time.

When materials and supplies are requisitioned from stores, entries are made in the issued and balance sections by the stores ledger clerk. The sum of the balances on the various stores ledger cards should equal the balance in the Stores control account.

Cost Ledger.—The cost ledger clerk makes the proper entries for requisitions in the materials section of the job order cost sheets. Where a great number of requisitions are to be accounted for, they are often summarized before entries are made on cost sheets. A convenient method is to have a **cost sheet jacket** with pertinent information appearing on outside and cost sheet and documents relating to costs of the order being accumulated inside the jacket for periodic posting to the cost sheet. Another method is to use some device for sorting requisitions by jobs or processes or in any other classification desired.

INVENTORY OVER AND SHORT REPORT.—When a physical count is taken, the actual balance is compared with the balance on the stock ledger card. In cases of overage or shortage, the stores ledger clerk adjusts the quantity on the ledger card. All differences are then summarized through an inventory over and short report, also called an inventory difference report (Fig. 4). This is done periodically. The report, taken from Heckert (Accounting Systems), forms the basis for a periodic **journal voucher** bringing the Stores controlling account into agreement with the adjusted stock ledger.

INVENTORY DIFFERENCE REPORT

DIVISION________ DATE________

NO. OF CARDS CHECKED______ NO. CORRECT______ NO. INCORRECT______

NO.	ITEM	COUNT	STORES RECORD QUANTITY	DIFFERENCE IN VALUE		
				UNIT VALUE	OVER	SHORT

Fig. 4. Inventory Difference Report

INVENTORY VALUATION.—The general rule of inventory valuation is cost or market, whichever is lower, but this is not definite enough, since there are many different kinds of cost. A published balance sheet may contain an asset "Inventory (at cost)," but this item might have different values opposite it, every one of which would represent some kind of cost. An incorrectly priced inventory may result in a false statement of profit or loss, with injury to stockholders and others. It may produce an erroneous statement of the working capital position and thereby make a misleading impression upon the creditor. It may also result in a substantial modification of the income tax to be paid. Correct inventory valuation is, therefore, at the heart not only of good cost accounting, but sound management as well.

METHODS OF COSTING.—When materials and supplies are issued to the factory, the quantities recorded on stock ledger cards must be translated into dollar values. Several methods of costing requisitions and pricing inventories are used, the most important of which are:

1. First-in first-out.
2. Weighted average.

3. Standard cost.
4. Last-in first-out.
5. Normal or base stock.
6. Cost or market, whichever is lower.

Some of the above methods are used both for pricing stores issues and for valuing inventory on hand at the end of period. Other methods are used exclusively for inventory valuation.

Original Cost or First-In First-Out Method.—The original cost or first-in first-out method assumes that items first received are the first to be issued, and that requisitions are priced at the cost at which these items were placed in stock. For example, if 100 units of material X are purchased at $1.00 per unit, and later 200 units at $.90, the first 100 units to be used are priced at $1.00 per unit, and the next 200 units at $.90

DATE	RECEIPTS		ISSUES			INVENTORY
	QUANTITY	UNIT COST	QUANTITY	UNIT COST	AMOUNT	QUANTITY
JAN. 5	100	$1.00				100
7			30	$1.00	$30.00	70
10	200	.90				270
15			70 }	1.00		
			40 }	.90	106.00	160
18	100	1.10				260
20			50	.90	45.00	210

FIG. 5. First-In First-Out Method

per unit. In the use of this method, care must be exercised in pricing requisitions filled from two or more lots (Fig. 5).

Weighted Average Method.—This method is used by those concerns which desire to spread total costs evenly over all goods on hand. To calculate the weighted average unit cost, the procedure is:

1. Add total quantity received to total quantity on hand.
2. Add cost of materials received to cost of those on hand.
3. Divide total values by total quantities.

The average is used in pricing requisitions and balances on hand until new purchases are received, when it is necessary to calculate a new average unit cost. The arithmetic involved in this method is illustrated in Fig. 6. The value of the ending inventory is found as follows:

1. Units on hand.................................. 210
2. Last average unit cost.......................... $ .99288
3. Value of inventory (210 × $.99288).............. $208.50

The weighted average method involves a considerable amount of detailed work in computing averages, in pricing requisitions, and in keeping stores records up to date. Again, high or low prices paid in the past for

DATE	RECEIPTS		ISSUES			INVENTORY
	QUANTITY	UNIT COST	QUANTITY	UNIT COST	AMOUNT	QUANTITY
JAN 5	100	$1 00				100
7			30	$1.00	$30 00	70
10	200	90				270
15			110	92593	101 85	160
18	100	1 10				260
20			50	99288	49 64	210

FIG. 6. Weighted Average Method

material are reflected in the average long after the material purchased at such high or low prices is consumed.

Standard Cost Method.—Under this method requisitions of materials are priced at some predetermined or standard cost. Only quantities of receipts and issues need be recorded on stores cards. See discussion of standard costs later in this Section.

Last-In First-Out Method.—This method of pricing requisitions, frequently called the **replacement cost method,** assumes that the last items purchased are the first to be used, the balance on hand being priced at the cost of the earliest purchases. By this method current income (sales) is charged at current (replacement) cost. For example, if 200 units of material X are purchased at 50 cents per unit, and later 400 units at 60 cents per unit, the first 400 units to be used are priced at 60 cents per unit, and next 200 units at 50 cents per unit. Care must be exercised in

DATE	RECEIPTS		ISSUES			INVENTORY		
	QUANTITY	UNIT COST	QUANTITY	UNIT COST	AMOUNT	QUANTITY	UNIT VALUE	TOTAL
JAN 5	100	$1 00				100	$1.00	$100.
7			30	$1 00	$30 00	70	1 00	70.
10	200	90				70	1 00	
						200	.90	250.
15			110	.90	99.00	70	1.00	
						90	.90	151.
18	100	1.10				70	1 00	
						90	.90	
						100	1 10	261.
20			50	1.10	55.00	70	1.00	
						90	.90	
						50	1.10	206.

FIG. 7. Last-In First-Out Method

pricing requisitions calling for two or more lots, and in recording balances on stores cards when two or more different priced lots are on hand.

The arithmetic involved in keeping stores records under this method is similar to that necessary under the first-in first-out procedure. The point to remember is that requisitions are priced at the cost of the most recent purchases (Fig. 7).

The principal advantage claimed for this method is that the cost of goods manufactured and sold during a period is stated more nearly at **current market** prices, and **unrealized inventory profits** are not reflected in the accounts. On the other hand, since inventories are valued at prices paid for the oldest goods, adjustments involving large amounts may be necessary to bring values into agreement with the cost or market rule. Proponents of this plan claim a greater stability of earnings from year to year, and that the resulting accounting records provide a better guide to management. It is favored particularly by industries where profits are inherently unstable, such as petroleum, tanning, and mining. It is now recognized by the Bureau of Internal Revenue for income tax purposes.

Normal or Base Stock Method.—A minimum amount of raw materials and supplies must be carried at all times as a reserve to meet production and customer needs. The minimum stock is valued at long-run "normal" prices and may be carried as a fixed asset, while the inventory in excess of the base stock is priced on some other basis, usually cost or market, whichever is lower. The theory underlying this method is that the base or normal stock is analogous to plant assets, representing in effect a fixed commitment of capital, and should be valued accordingly. The particular items making up the inventory, it is admitted, are constantly changing, but the value, it is held, remains undisturbed as long as the volume of goods is maintained at the normal level.

The base stock plan is supported in the smelting, tanning, and oil refining industries on the ground that earnings from year to year are more uniform and stable than under other methods.

Cost or Market, Whichever Is Lower.—This method of valuation is a combination of the actual cost and replacement cost plans. It is the basis of valuation used by most accountants and is interpreted to mean actual cost or replacement cost, whichever is the lower. The term "market" or replacement cost is defined by the Bureau of Internal Revenue as "the current bid price prevailing at the date of the inventory for the particular merchandise in the volume in which usually purchased by the taxpayer." It should be observed when this basis is used that "the market value of **each** article on hand at the inventory date shall be compared with the cost of the article, and the lower of such values shall be taken as the inventory value of the article." The cost or market rule is recognized by the Bureau of Internal Revenue in valuing inventories for income tax purposes, and is approved by most accountants and business men.

Scrap, Waste, and Spoilage

SCRAP DEFINED.—Scrap consists of fragments or remnants of material that remain after certain manufacturing operations or processes have been completed, and that have some monetary or use value. It is

a form of raw material that may be sold in the open market, used as raw material in manufacturing operations, or used as supplies in various departments of a plant.

Scrap is brought into existence in metal industries through the operations of cutting, boring, punching, turning, etc.; in woodworking plants by sawing, shaving, trimming, etc.; in leather and garment manufacturing industries through cutting and trimming operations.

WASTE DEFINED.—Waste as contrasted with scrap is often considered as having no value and is treated as a loss. On the other hand, the terms scrap and waste are frequently used interchangeably. For example, the following definition of these two terms is found in Amidon and Lang (Essentials of Cost Accounting):

> Waste or scrap may be defined as small pieces of material which cannot be utilized for the purpose originally intended, but from which some recovery may be had.

The effect of waste is to increase the unit cost of production, since the total cost is spread over a smaller number of units produced. The general practice is to include in direct cost the lost value of items scrapped in a process. By this is meant the absorption in the cost of the good units finished of all material, labor, and overhead less the **salvage value** of the rejected items.

DEFECTIVE WORK AND SPOILAGE DEFINED.—Defective work consists of imperfect products which are brought up to standard specifications by the application of additional material or labor, or both. These items constitute **reoperation costs** incurred in remedying imperfections so that the product meets the required standards of quality.

Spoilage results when materials are so damaged in manufacturing operations that they are taken out of process and disposed of in some manner without further work. Spoiled materials cannot be repaired or reconditioned as is done in the case of defective work. In some cases spoiled work must be sold as seconds as in hosiery manufacturing, but in others it can be salvaged as scrap and either sold or used over again as raw materials in the manufacturing processes. In either case there is not only a material loss in the product, but there is a loss also of labor and manufacturing overhead already incurred on the material.

ACCOUNTING FOR SCRAP, WASTE, AND SPOILAGE.—Since it is often difficult to allocate scrap to a particular job, it may be credited to general factory overhead, or revenue derived from its sale may be treated as "Miscellaneous Income."

Waste material is assumed to have no value, hence no accounting entries are necessary. The value of materials wasted is already included in the production costs when direct materials are charged to job orders or to processes.

The **cost of defective work** may be treated as follows (Amidon and Lang, Essentials of Cost Accounting):

1. Treatment by neglect; i.e., absorbing the loss by spreading the total cost over the good units completed.
2. Charging general overhead.
3. Charging department responsible.
4. Costing work involved in reconditioning defective work.

If spoiled work can be sold at scrap or junk prices or used in some manner in the plant, provision should be made to remove from the Work in Process account all costs incurred up to the point of spoilage. This is the procedure to be followed in the case of **government contracts;** a manufacturer is permitted to include the normal amount of spoilage and defective work in the cost of the work performed, due recognition being given for abnormally rapid expansion of production. Government contracts also require that the value of any scrap resulting from war production must be taken into account at proper current scrap prices whether or not the scrap is sold.

Labor Costs

DIRECT AND INDIRECT LABOR DEFINED.—For cost accounting and control purposes the general rule is that direct labor is labor spent in actual production of the product, i.e., labor immediately identifiable with product costs.

It may cover special premiums, bonuses, overtime payments, compensation insurance, old age benefit and other social security taxes. These should all be separately stated.

Indirect labor represents auxiliary work done in connection with product manufacture. It is labor that is not engaged in changing the form of the product, but which performs essential services. Wages of indirect workers who spend all their time in one department represent **direct departmental overhead.** Examples are: departmental foremen, assistant foremen or gang bosses, timekeepers and other departmental clerks (where they work in only one department), departmental tool setters, machine adjusters, and inspectors, etc.

Other classes of indirect workers have duties which take them into several departments, or their work is for the benefit of a number of departments. Hence, their pay is prorated to the departments served. This cost is a part of the **general factory overhead.** Examples are: general manager, factory superintendent, general foremen, rate clerks in factory office, time study department, schedule clerks, route clerks, chief inspector, etc.

TIMEKEEPING, LABOR COSTING, AND PAYROLL PREPARATION.—Fig. 8, adapted from Bangs (Factory Management), illustrates in the form of a flow chart the relation between timekeeping, payroll accounting, and labor costs. The illustration covers the sequence of steps for one direct worker and one indirect worker (trucker). Dispatching and attendance are part of the functions of a timekeeping department; the latter feeds its data into the payroll department where the attendance records (clock cards) and the work records (job time cards) are compared. The completed payroll in turn forms the basis for charges to cost controlling accounts while detailed labor cost distributions are posted directly from the job time cards by the cost department.

TIME RECORDING.—Time may be recorded on time tickets (Fig. 9) through mechanical devices or handwritten records. Electric job recorders located at various points in the plant, or in a central timekeeping department, are often used to stamp the start and finish times for each

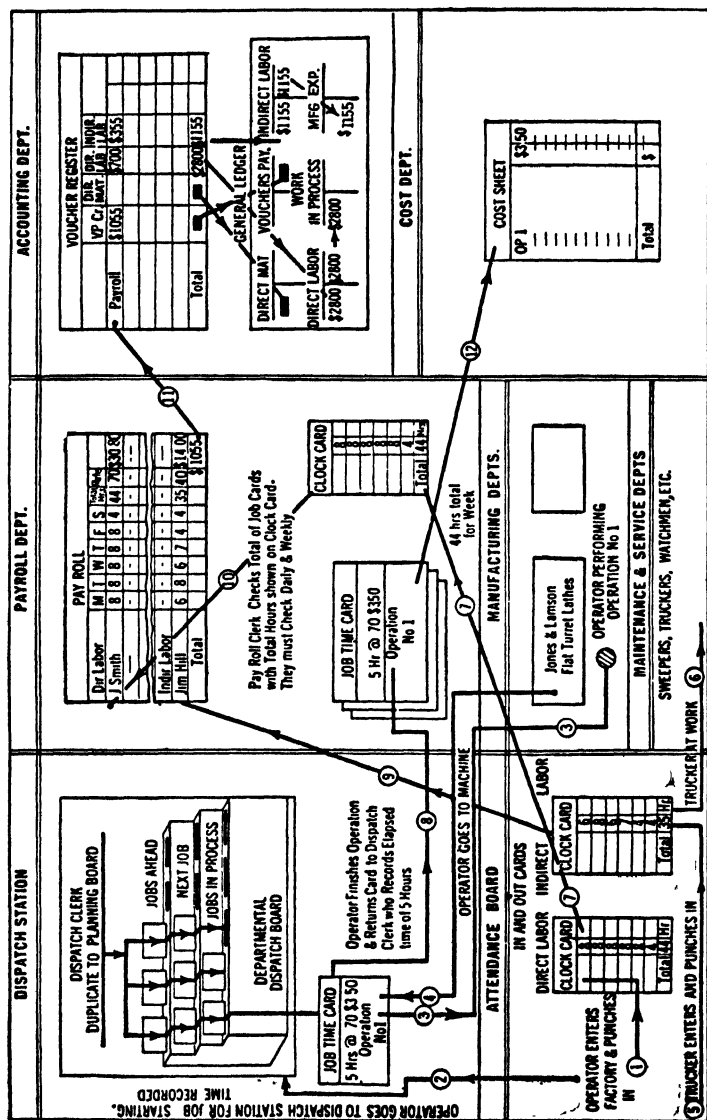



Fig. 8. Chart Showing Relation between Timekeeping and Other Labor Functions

EMPLOYEES NO. AND NAME DK7F

RETURNED | CHARGE TO DK7F1N

ISSUED | SHOP DK7F

ARTICLE | PART PRIME | LOT NO.

OPER. NO | OP. SYMBOL | MACH. SYMBOL 1PPH

INSTRUCTIONS

DAY WORK

ORIG QUANT. TO DO

QUANTITY TO DO	QUANTITY FINISHED	MACHINE HOURS	OPERATION HOURS	RATES			OPERATION COST	MACHINE COST
				PIECE	MACH.	HOUR		

FIG. 9. Time Ticket

job. Another type of recorder computes and stamps the elapsed time automatically.

In some plants the use of **preprinted time tickets** in the form of detachable coupons is possible. Upon receipt of bills of materials or blueprints, a time setter prepares a time card for each operation or each job. He shows the time allowed for the operation and the machine or group of machines on which the operation is to be done. The time card then serves both as a work assignment and as a record of time actually spent on the job, as compared with the time originally estimated.

COMBINING CLOCK RECORD AND LABOR DISTRIBUTION.—Conventional methods call for in-and-out clock record and use of separate time tickets. This makes it necessary for two sets of clerks to handle the records and then to reconcile the figures obtained by each section. By combining both types of record into a single form, reconciliation of labor charges and payroll earnings becomes automatic. Fig. 10 illustrates this type. The top of the form is used as a **clock card** and also as a payroll stub. Below the payroll stub are six **cost coupons** showing production, time spent, rate, amount earned, charge and operation number, for each job worked on during the day. Each morning the cards are picked up by the timekeeping department and checked as to time between clock rings, quantities, charge numbers, operation numbers, and rates. The cards are then sorted by departments.

Extensions on the above time cards are handled by electric calculators. At the same time, the machine accumulates the departmental totals automatically. These departmental totals are then posted to a payroll control sheet.

Labor distributions are obtained by sorting the cards by employees within the departments; the cost coupons are cut from the payroll stubs

for sorting on spindles. Information on the payroll stubs is posted to the employees' earnings records. The coupons are next sorted by departments and account charges. The resulting figures are then posted to a **departmental labor distribution sheet.** The sum total of all the

No 51171
50-759
HENRY JONES
SHIFT 3 | GROUP | EXTRA CARD NOS | 2.2 | 1.0 | 12.0 | 6.0
SIGN HERE
Henry Jones
FOREMAN'S APPROVAL
TOTAL HOURS | TOTAL AMOUNT

CHARGE	OPER NO	
201	50	No 51171
QUANTITY	RATE	AMOUNT
120	.007	84
HOURS	RATE	

CHARGE	OPER. NO	
216	65	No 51171

Fig. 10. Combined Clock Record and Cost Coupons

charges in all departments must be balanced against the payroll control sheet.

At the end of the month, labor charges are totaled by adding the columns on the labor distribution sheets. Grand totals for the labor distribution sheets, payroll control sheet, and employees' cards must be in balance.

LABOR DISTRIBUTION.—The purpose of payroll accounting is to lay the basis for the payment of wages and salaries to the employees. By contrast labor distribution is strictly a cost function in that it assigns payroll costs to costs of production and distribution. The final step in payroll accounting is the creation of a charge to a Payroll account and a credit to a liability, Payroll Accrued, which is liquidated on pay day. The aim of labor distribution is to break down the charge to Payroll, to show its component parts, and then to make the distribution entry to close out the payroll account.

At the end of a week or month, the departmental payroll analysis sheets are summarized on a payroll summary. Totals of this summary provide the information for the monthly journal voucher covering labor distribution. In this way Work in Process is charged for the cost of direct labor, and Manufacturing Expense for indirect labor. The appropriate subsidiary or detailed records must also be posted. These cover:

1. For direct labor: Individual job cost sheets or process accounts.
2. For indirect labor: Departmental expense record.

Overhead Accumulation

MANUFACTURING EXPENSE DEFINED.—Raw materials and direct labor combined are termed prime cost. Superimposed upon prime cost is a class of indirect or general expenses which, though pertaining to manufacturing, cannot be charged directly to the product. These expenses are termed manufacturing expense or burden.

The term **overhead expenses** is commonly used as a synonym for burden. It is a collective term that includes all items of manufacturing expense. Other synonyms are factory expense, plant expense, plant and service expense, factory overhead, oncost, factory service, etc.

PRIMARY MANUFACTURING EXPENSE ACCOUNTS.—In order to differentiate overhead expenses from expense classifications on a functional basis, they are often referred to as primary expenses. A typical subdivision of primary manufacturing expenses is shown below.

31. Salaries and Wages
32. Operating Supplies
33. Other Factory Expenses
34. Rendered Service
35. Maintenance
36. Fixed Charges
37. Power, Heat, and Light
38. Sundry Expenses

These major primary account groups are subdivided, viz.:

SUBGROUP 31. SALARIES AND WAGES
- 311 Supervision
  - 3111 Supervision
  - 3112 Foreman and Assistants
  - 3113 Inspectors
- 312 Clerical Employees
  - Etc.

BEHAVIOR OF MANUFACTURING EXPENSES.—Manufacturing expenses are also classified according to the degree of their variability. This classification discloses a threefold group of expenses as follows:

1. Variable expense items.
2. Nonvariable expense items (fixed charges).
3. Partly variable expense items.

VARIABLE EXPENSES.—A variable expense item is one whose total changes in proportion to changes in output. Doubling the output doubles the expense. There are very few expense items which are either 100% variable or 100% fixed. Note that variable expenses are those whose totals change. Expressed in terms of unit costs, this type of expense shows constant costs.

NONVARIABLE AND PARTIALLY VARIABLE MANUFACTURING EXPENSES.—Nonvariable expenses are commonly referred to as fixed charges. Few manufacturing expenses are 100% fixed. A fixed charge is defined as one whose total remains constant, or whose total does not change with changes in output within the limits

of plant capacity. When plotted, fixed charges are represented by a horizontal line.

A **partially variable** or semi-variable manufacturing expense item is one that varies with production within certain limits, and remains constant at some stages of productive output. Such items increase in amount as production increases, but the increase is not uniform as in the case of variable expenses.

DEPARTMENTAL EXPENSES.—A twofold analysis of all factory expenses, by objects of their expenditure, and by departments (producing and service) to which the expenses apply, is a requisite cost accounting procedure. To these ends, the **primary expense accounts** are broken up and allocated to departmental accounts. Hence, a good many expense accounts are common to all departments. For example, office supplies, indirect labor, supervision, clerical, maintenance, etc., are to be found to a greater or lesser degree in all departments. This calls in effect for two ledgers subsidiary to the same controlling account. The Manufacturing Expense account controls the primary expense or manufacturing expense ledger. The accounts in the latter are then distributed to the departments either in a departmental expense ledger or on an expense distribution sheet.

Direct and Indirect Charges.—All expenses incurred in the operation of departments are charged to their respective departmental accounts. These expenses may be further subdivided into:

1. Direct departmental expenses.
2. Indirect departmental expenses.

Direct expenses are those charges which in the first instance can be identified with a particular department. **Indirect expenses** represent service department charges prorated from other departments; thus, all indirect expenses are direct charges to service departments, and when redistributed become indirect charges to the producing departments.

Overhead Distribution

ALLOCATION AND PRORATION OF MANUFACTURING EXPENSES.—The distribution of expenses falls into two groups:

1. Those expense items which can be identified directly with specific departments. Such identification is known as expense allocation.
2. Certain joint expense items which must be distributed among two or more departments. This process is known as proration.

In practice the terms allocation, proration, and distribution are used more or less synonymously.

PRIMARY EXPENSE DISTRIBUTION.—A primary expense distribution represents an attempt to assign manufacturing expenses to particular departments either through precise measurement or through a process of estimating. Where expense items can be directly identified with departmental operations no particular problem arises, because the expense allocation is determined on the basis of benefit derived and is capable of exact quantitative measurement. Thus, where departmental meters are installed to measure the consumption of light or power the

resulting cost allocation can be said to be exact. If, however, a single plant meter measures the over-all consumption of light and power, the proration of these expenses results in estimated departmental costs for these expense items. All prorations are therefore estimates and as such subject to the limitations of all cost estimates. Usually no one basis of proration is free from objection, and the cost accountant is bound to effect some compromise between a theoretically perfect method and one that is suited to the practical exigencies of the local conditions. A distribution of light expense on an area basis may be perfectly satisfactory in one plant where the lighting system is uniform, and the ceiling heights do not vary. But where some departments require special lighting, such as mercury arc, fluorescent, indirect, etc., and where different light intensities are required, and ceiling heights vary, obviously an area basis is out of the question. As nearly as possible some basis of distribution must be selected that takes into account all the factors likely to exert an influence on the behavior of the **standing order expense** in question.

Such items as building depreciation, building insurance, building maintenance, and even building taxes are quite commonly prorated on a floor area basis. Heat, if it is not meter-measured, may be distributed on the basis of the cubic content of the various departments, or the floor area, or the square feet of radiation. Similarly, lighting expense may be prorated on the basis of floor area, cubic content, number of outlets, kilowatt-hours, etc.; power may be distributed on the basis of rated capacities of machines, machine-hours, horsepower-hours, or even direct labor hours. Some physical coefficient is always used to effect the distribution. In each case the expense is expressed as a cost per unit and the primary distribution made by multiplying the actual or estimated numbers of units consumed in each department by the unit cost.

EXPENSE DISTRIBUTION SHEET.—The design of the expense distribution sheet is illustrated in Fig. 11; it is usually prepared on columnar analysis paper. Specific expense accounts should be arranged in the left-hand margin in exactly the same order as they are arranged in the subsidiary **expense ledger.**

After the subsidiary expense ledger balances are proved with their control account at the end of each month, the balances are transferred to the grand total column of the expense distribution sheet. The totals of each account are then distributed among the departmental columns. This constitutes the **primary expense distribution,** and consists of spreading actual expenses over the producing and service departments to which they apply on the basis of information contained on original vouchers or expense analyses. In this way each department is charged with its share of variable, semi-variable, and fixed expenses, and all expenses constituting direct charges to departments appear under their proper headings.

The final stage in the completion of the expense distribution sheet consists of making the **secondary expense distributions.** This involves a redistribution of service department expenses in such a way that ultimately all expenses are lodged in producing department accounts. Such a distribution constitutes an indirect or redistributed charge to the department receiving it. It is made necessary because the product travels through the producing departments only and must therefore absorb the entire plant overhead in those departments.

CODE	NAME	PRODUCING DEPARTMENTS						SERVICE DEPARTMENTS						
		GRAND TOTAL	90 MACHINE SHOP	91 FINISHING	92 HEAT TREATING	93 ASSEMBLY	SUB-TOTAL	01 ENGINEERING	02 TOOLROOM	03 STORESROOM	04 FACTORY ACCOUNTING	05 GENERAL PLANT	06 POWERHOUSE	SUB-TOTAL
501	Factory Supplies.......	$ 2,968.65	$ 1,021.12	$ 745.98	$ 624.42	$ 246.63	$ 2,638.15						$ 330.50	$ 330.50
502	Small Tools............	1,919.24	589.27	642.87	81.07	491.63	1,804.84						19.50	114.40
503	Factory Office Supplies													
504	Fuel..................													
505	Water..................													
506	Defective Work Losses..													
507	Repair Materials, Equipment............													
508	Repair Labor, Equipment													
509	Miscellaneous Factory Expenses............													
510	Workmen's Compensation Insurance............													
511	Social Security Taxes..													
512	Material Handlers......													
513	Helpers................													
514	Service Attendants.....													
530	Foremen................													
531	Departmental Heads and Assistants...........													
532	Factory Office Clerks..													
550	Medical Services.......													
551	Patents Amortization...													
552	Depreciation, Buildings													
553	Depreciation, Equipment													
554	Insurance, Building....													
555	Insurance, Equipment...													
556	Taxes, Building........													
557	Repairs and Maintenance, Buildings............	723.33	250.00	65.00	50.00	75.00	440.00	$ 40.00	$ 20.00	$ 83.33	$ 25.00	$ 15.00	$ 100.00	$ 283.33
558	Relining Expense.......	433.33	-	-	433.33	-	433.33							
	Total Direct Expenses..	$77,911.71	$29,167.67	$ 8,859.80	$ 7,744.70	$ 5,039.54	$50,811.71	$ 3,300.00	$ 3,700.00	$ 3,800.00	$ 2,100.00	$ 2,200.00	$12,000.00	$27,100.00

[Detailed figures purposely omitted.]

FIG. 11. Primary Expenses on Manufacturing Expense Distribution Sheet

BASES FOR DISTRIBUTING SERVICE DEPARTMENT EXPENSES.—Some methods commonly used to distribute service department expenses are as follows:

1. Meter readings or engineers' estimates.
2. Number of employees, total labor hours, or total labor dollars.
3. Direct charges to productive departments.
4. Relative floor space area.
5. Specific application to repair or new work orders.
6. Machine-hours.
7. Truck-hours.
8. Crane-hours.
9. Cubic content.
10. Property valuation, etc.

There is no uniform application of a particular basis in the distribution of a given service department. The choice of a basis is either a matter of individual bias, or depends on the existence of some specific condition. If possible the basis chosen should bear some logical relationship to the expense item. If it can be established that a certain expense varies with area, then the latter becomes the logical basis for distribution.

PROCEDURE IN SECONDARY DISTRIBUTION.—The most common plan is to make service department expense distributions on a so-called nonreciprocal basis. By this plan, cognizance is taken of the fact that services rendered by certain service departments are in part utilized by certain other service departments and distributions are made accordingly. This means, for example, that a portion of power plant expense is distributed to the toolroom, because the power plant provides a service to the toolroom. But, in turn, no part of toolroom expense is distributed to the power plant, even though the toolroom actually rendered some service to it.

Arrangement of Work Sheet.—When service department expense distributions are made to other service departments on a nonreciprocal basis, the arrangement of service department columns on the expense distribution sheet must be carefully planned. Those service departments which provide the greatest number of distributions to other service departments should be placed at the extreme right-hand side of the distribution sheet. In passing from right to left on the work sheet, each service department has at least one less distribution than the column on its right; that is, expense distributions are made in column order from right to left in stepping-stone fashion. As soon as each distribution is computed, it is posted to the expense distribution sheet, thus closing out a specific departmental column. The next column immediately to the left is then totaled and this total is used in making a distribution to any or all departmental columns to the left. When all service departments have been thus distributed, the producing department columns are subtotaled, and the subtotals are added to the subtotal of the direct charges to obtain the grand totals. This is illustrated in Fig. 12, which represents the lower half of the expense distribution sheet shown in Fig. 11.

After all service department expenses have been distributed, the total service expenses are lodged in the producing department accounts. These totals may be reduced to expense rates to be used in charging production.

MANUFACTURING EXPENSE DISTRIBUTION FOR JANUARY, 19—

EXPENSE ACCOUNT		GRAND TOTAL	PRODUCING DEPARTMENTS					SERVICE DEPARTMENTS						
			90	91	92	93		01	02	03	04	05	06	
CODE	NAME		MACHINE SHOP	FINISHING	HEAT TREATING	ASSEMBLY	SUB-TOTAL	ENGINEERING	TOOLROOM	STORESROOM	FACTORY ACCOUNTING	GENERAL PLANT	POWERHOUSE	SUB-TOTAL
	Total Direct Expense......	$77,911.71	$29,167.67	$ 8,859.80	$ 7,744.70	$ 5,039.54	$50,811.71	$ 3,300.00	$ 3,700.00	$ 3,800.00	$ 2,100.00	$ 2,200.00	$12,000.00	$27 100.00
	Service Department Distributions.													
5506-1	Heat....................		$ 845.73	$ 230.65	$ 172.99	$ 249.88	$ 1,499.25	$ 134.55	$ 57.67	$ 172.99	$ 38.44	$ 19.22	$ 1,922.12	
5506-2	Light....................		302.33	79.18	57.59	86.38	525.48	50.39	21.60	79.18	28.79	14.40	719.84	
5506-3	Power....................		6,838.57	899.81	1,079.77	179.96	8,998.11	-	359.93	-	-	-	9,358.04	
													$12,000.00	
5505	General Plant...........		625 41	759.43	178.69	446.73	2,010.26	44.67	44 67	89.35	44.67	$ 2,233.62		
5504	Factory Accounting......		641.45	774.16	176.95	442.38	2,034.94	44.24	44 24	88.48	$ 2,211.90			
5503	Storesroom.............		2,538.00	423.00	253.80	972.90	4,187.70	-	42.30	$ 4,230.00				
5502	Toolroom...............		1 195.72	1,793.57	341.63	939.49	4,270.41	-	$ 4,270 41					
5501	Engineering............		1,786 93	893.46	357.39	536.07	3,573.85	$ 3 573 85						
	Total Service Expense Distributions...........		$14,774 14	$ 5,853.26	$ 2,618.81	$ 3,853.79	$27 100.00							
	Total Direct and Indirect Producing Departments Expense................		$43,941.81	$14,713.06	$10,363.51	$ 8,893.33	$77,911.71							

FIG. 12. Service Department Expense Distributions Made to Producing and Service Departments on a Nonreciprocal Basis

Overhead and Product Cost

ACTUAL VS. PREDETERMINED OVERHEAD RATES.—Overhead may be applied to the product on the basis of rates established either after or before the expenditures are actually ascertained. If an overhead rate based on actual costs is to be used, the following formula results:

$$\text{Actual rate} = \frac{\text{Actual overhead for period}}{\text{Actual production for period in units, hours, or dollars}}$$

If a predetermined rate is to be used, the following formula obtains:

$$\text{Predetermined rate} = \frac{\text{Estimated overhead for period}}{\text{Estimated production in units, hours, or dollars}}$$

When **actual overhead** is used, the costing procedure cannot be completed until the close of the period. Often this delay is disadvantageous, since final costs on completed work cannot be determined for some time after the order is finished, and, in general, the work of the accounting department is delayed.

An **estimate of actual overhead** for the year, determined in advance and applied on the basis of a uniform rate throughout the period, smooths out the monthly cost picture. The resulting unit costs are in a sense average costs and for that reason are more nearly representative costs than the actual costs. Predetermined **normal overhead costs** show what the unit costs might be under controlled spending conditions in relation to capacity operation even though the plant does not operate at capacity.

METHODS AND DATA FOR ESTABLISHING BURDEN RATES.—If actual burden rates are to be used, the necessary data are:

1. Production, measured in units, weight, volume, hours, dollars, etc.
2. Factory overhead, in total, by expense classifications, and by departments.

Data regarding production are obtained from appropriate plant production reports. Information concerning factory overhead is derived

Bases for Establishing Rates	Subdivisions for Rate Determination	Methods for Applying Rates to Products
I. Actual Costs (post-determined)	Blanket	1. Percentage of direct labor dollar. 2. Rate per direct labor hour. 3. Amount per unit of product.
II. Expected Actual Costs (pre-estimated)	Departmental	4. Percentage of direct material cost. 5. Percentage of prime cost. 6. Percentages based on market values.
III. Normal Costs (predetermined)	Cost Center	7. Supplementary rates. 8. Rate per machine-hour.

FIG. 13. Chart Showing Methods of Overhead Application

METHOD	FORMULA		WHERE USEFUL
1. Direct Labor Dollar Method	$\frac{\text{Overhead}}{\text{Direct labor dollars}}$	= % of overhead per direct labor dollar	Labor the main productive element; no material pay rate differences.
2. Direct Labor Hour Method	$\frac{\text{Overhead}}{\text{Direct labor hours}}$	= Rate per direct labor hour	Labor the main productive element; pay rate differences preclude using (1).
3. Machine Hour Method	$\frac{\text{Overhead for machine}}{\text{Machine hours}}$	= Rate per machine hour	Machines the main productive element; no uniform relationship between machine time and man time.
4. Unit of Product Method	$\frac{\text{Overhead}}{\text{Number of units of product (each, weight, points)}}$	= Overhead cost per unit of product	One product mass-produced; or a few products of great uniformity that can be related by weight or by a point system.
5. Material Cost Method	$\frac{\text{Overhead}}{\text{Direct material cost}}$	= % of overhead per direct material dollar	Most useful to apply material burden; also, in special departments and for special processing of materials.
6. Prime Cost Method	$\frac{\text{Overhead}}{\text{Direct material cost} + \text{Direct labor cost}}$	= % of overhead per dollar of prime cost	In special situations only; material and labor costs, together, should follow a uniform pattern; considered antiquated.
7. Market Value Method	$\frac{\text{Market value, product A}}{\text{Total market value, all products}}$	= % of overhead apportioned to product A	For joint products.
8. Supplementary Rates	$\frac{\text{Actual overhead} - \text{Absorbed overhead}}{\text{Hours, dollars, or units}}$	= Supplementary rate	To obtain actual overhead cost for product where a predetermined rate has been used; to modify costs during period without changing main rates.
9. Blanket Rates	$\frac{\text{Total overhead for plant}}{\text{Total hours, dollars, or units}}$	= Blanket rate	Where one product is made in continuous process; where a few related products are made, involving the same time and effort at each stage.
10. Departmental Rates	$\frac{\text{Direct department overhead} + \text{Apportioned overhead}}{\text{Hours, dollars, or units for department}}$	= Departmental rate	Where diverse products are made; where differences in processing occur.

METHOD	FORMULA	WHERE USEFUL
11. Departmental Hourly Cost Rate	$\frac{\text{Direct labor cost for department + Departmental overhead}}{\text{Hours, dollars, or units for department}}$ = Departmental hourly cost rate	Where departmental rates are used and ease of calculating unit costs is desired; where direct labor as a separate element becomes less distinct.
12. Cost Center Rates	$\frac{\text{Direct overhead for cost center + Apportioned overhead}}{\text{Hours, dollars, or units for cost center}}$ = Cost center rate	Where departmental rates are not accurate; i.e., departments not homogeneous cost units.
13. Cost Center Hourly Cost Rate	$\frac{\text{Direct labor cost for cost center + Cost center overhead, direct and apportioned}}{\text{Hours, dollars, or units for cost center}}$ = Cost center hourly cost rate	Where cost center rates are necessary and ease of calculating unit costs is desired; where direct labor as a separate element is less distinct.
14. Normal Rates	$\frac{\text{Budgeted overhead at normal capacity}}{\text{Normal production in hours, dollars, or units}}$ = Normal rate	Where it is desired to eliminate from unit costs and inventory values fixed charges applicable to excess capacity; where it is desired to level unit costs for overhead over a period of years (possibly the business cycle); to relate overhead costing to standard costs and budgetary control. (applies to 14 and a–c)
a. Standard Direct Labor Dollar Method	$\frac{\text{Normal overhead}}{\text{Standard direct labor dollars}}$ = Standard rate per standard direct labor dollar	
b. Standard Direct Labor Hour Method	$\frac{\text{Normal overhead}}{\text{Standard direct labor hours}}$ = Standard rate per standard direct labor hour	
c. Standard Machine Hour Method	$\frac{\text{Normal overhead}}{\text{Standard machine hours}}$ = Standard rate per standard machine hour	
15. Standard Productive Hour Method	$\frac{\text{Standard direct labor dollars + Normal overhead, direct and apportioned}}{\text{Standard productive hours}}$ = Standard rate per standard productive hour	Combines advantages of normal rates with cost center hourly rates.

Fig. 14. Summary of Overhead Formulas and Their Use

from expense distribution sheets and other sources discussed under Overhead Accumulation and Overhead Distribution earlier in this Section.

If **predetermined rates** are to be used in applying overhead, it is necessary to estimate the production and the amount of overhead expenses in advance. In such cases appropriate **budgets** representing a combination of past experience and future expectation supply the requisite data.

Fig. 13 shows graphically the classification of methods of overhead application and their relation to each other. The first column lists the fundamental types or bases upon which rates may be established. Each of these is further subdivided as shown in the second column of the diagram. The third column lists the specific methods of burden application. Of these the first seven may be used in conjunction with any of the subdivisions in column two. The last one, the machine-hour rate, is used only in connection with cost centers or specific machines.

In the presentation of the methods in Fig. 14, it is to be understood that each formula may be for the factory as a whole, for each department in the plant, or for each cost center. The numerator for overhead and the denominator representing the base may be expressed in terms of actual, estimated actual, or normal figures. By keeping the numerator and denominator on the same basis, the resulting percentages represent, respectively, actual, estimated actual, or normal rates.

SUMMARY OF OVERHEAD FORMULAS AND SELECTION OF METHOD.—Formulas for the various methods and conditions favoring their use are presented in Fig. 14. Certain points may be listed as guides in selection of correct method for application of overhead to product in specific cases:

1. Method selected should use as its base the **main productive element** in the particular manufacturing operation; i.e., it should relate indirect factory expenses to the product in a logical way.
2. **Separate rates** should be established for each area that constitutes a homogeneous cost unit from the point of view of obtaining correct product costs. In some cases, this may mean **cost center or operation rates**; in others, **blanket rates.**
3. The method should eliminate from product cost unwarranted fluctuations in unit costs occasioned by radical volume changes. In some companies, this problem may not exist in excessive form, and actual, or an estimate of actual, rates may suffice. In a majority of companies, normal rates are necessary.
4. The method or methods adopted should make possible monthly **profit and loss statements** of operating significance, as well as facilitate the compilation of special reports.
5. Other things being equal, **departmental rates** or cost center rates are superior to blanket rates, because of the greater flexibility of the former.
6. Other things being equal, **rates based on time** (labor-hours, machine-hours, etc.) are preferable to rates based on a variable cost factor (labor dollar, material cost, etc.). This is because many important expense items, particularly fixed charges, are functions of time (depreciation, fire insurance, rent, etc.), and cost factors may not move in step with changes in overhead.
7. The method adopted should be practical; but not so "practical" as to give the wrong cost data, nor so simple as to yield information of no use.

Direct Labor Dollar Method.—Fig. 15, adapted from Bennett (N.A.C.A. Bul., vol. 19), illustrates the method for calculating departmental and blanket direct labor cost burden rates.

NAME	Basis of Distribution	Estimated Total	Mill Room	Machine and Cabinet	Finishing	Upholstering	Plating	Packing	General Factory
Total Manufacturing	Expenses..........	$83,225	$1,730	$27,055	$11,395.80	$3,049.00	$675	$2,100	$37,219
Distribution of General Factory and Plating.....	Total payroll		1,478	20,842	11,027.70	3,107.29		1,440	
Total Factory Burden.....	....	$83,225	$3,208	$47,897	$22,423.50	$6,156.29		$3,540	
Direct Labor	....	$94,757	$4,004	$51,181	$27,718.00	$7,852.00		$4,004	
Burden Rates	....	87.8%	80.2%	93.5%	80.9%	78.4%		88.4%	

FIG. 15. Direct Labor Cost Rates

On the cost card for a specific lot or style number, the following burden figures would result from the given payroll data:

	Labor	%	Burden
Mill Room	$ 7.00	80.2	$ 5.61
Machine and Cabinet	25.00	93.5	23.38
Finishing	30.00	80.9	24.27
Upholstering	35.00	78.4	27.44
Packing	3.00	88.4	2.65
Total Labor and Burden	$100.00		$83.35

The use of a blanket rate produces an overhead cost of $87.80 (i.e., $100 × 87.8%) as compared with $83.35 above.

Direct Labor Hour Method.—Schroedel (N.A.C.A. Bul., vol. 18) uses actual expenses in computing labor hour rates for a concern manufacturing uniforms as follows:

Department	Actual Expense	Direct Labor Hours	Rate
Cutting Room	$1,377.12	1,000	$1.38
Trimming	538.79	400	1.35
Coat Shop	3,566.94	4,000	.89
Pants Shop	2,143.21	3,000	.71
Bullion Department	260.64	200	1.30
Cap Department	208.80	200	1.04
Total	$8,095.50	8,800	$ .92

Machine-Hour Rate.—The computation of the rate may be expressed as a formula:

$$\frac{\text{Overhead expense for specific machine}}{\text{Estimated machine-hours}} = \text{Rate per machine-hour}$$

The estimated hours may take into account the time for **set-ups**, or as in some cases, separate rates may be set for set-up and for running time.

There are three steps in computing machine-hour rates:

1. Determination of the estimated overhead expenses for the period, by departments. This may take the form of a budget, set up in the form of an **expense distribution sheet.**
2. Regrouping of these expense items into:
   a. Specific charges to each machine, such as power, maintenance, etc.
   b. Prorated charges, such as heat, supervision, etc.
3. Machine costs, direct and prorated, are combined to obtain total overhead expense to operate each machine during the year. The machine rate is derived by dividing this total by the number of hours of operation.

Overhead is then costed to the job or process by multiplying this rate by the number of machine hours taken on each operation. Thus, if it is estimated that a given turret lathe is to be operated 1,500 hours during coming year, with an estimated overhead expense of $3,300, the machine-hour rate is $2.20 found by dividing $3,300 by 1,500 hours. That is, for each hour of machining on the turret lathe there is to be added $2.20 for overhead expense. If part X-127 required 45 minutes for machining on this turret lathe, the overhead costed against the part is $1.65 (i.e., $2.20 × .75 hour).

Unit of Product Method.—Bennett (N.A.C.A. Bul., vol. 16) uses a blanket rate in a shoe plant as follows:

Total burden	$57,436
Number of pairs of shoes	200,000
Burden per pair	$.287

Each style of shoe manufactured is then charged for overhead at the above rate per pair.

Material Cost and Prime Cost Methods.—Overhead may be applied to production on the basis of the cost of direct material consumed, or even the prime cost (material and labor). Neither method is popular. However, some use is found for the material cost method as a means of distributing a portion of overhead expense known as **material burden** comprising the costs of purchasing, receiving, testing, storing, and handling raw materials. Used in this manner it constitutes a **secondary rate,** the principal portion of overhead being distributed by one of the other methods.

Supplementary Rates.—Supplementary rates are used to adjust the amount of overhead costed into production on a predetermined basis to the actual amount for the period. As the name implies, they are used in connection with other rates at the close of a period to absorb over- or underapplied expense. They may be illustrated as follows:

Actual overhead on turret lathe	$3,560.00
Absorbed overhead (1,450 hours × $2.20 per hour)	3,190.00
Unabsorbed overhead	$ 370.00
Supplementary rate ($370 ÷ 1,450 hours)	$ .255
Overhead cost for Job X–127:	
Machine-hour cost (75 hours × $2.20)	$ 165.00
Supplementary cost (75 hours × $.255)	19.12
Actual overhead cost	$ 184.12

Cost Center Rates.—Cost centers (also designated burden centers or production centers) are units, functions, or areas within an establishment that are homogeneous from the cost point of view. They are natural divisions of an organization for **cost finding** purposes. It is sometimes advantageous to combine direct labor and overhead costs in a cost center to obtain the total cost of operation, exclusive of direct material. This total, divided by the expected number of hours of operation, yields a cost center hourly cost rate, an over-all rental charge for the use of all facilities in the center.

The computation of a cost center rate for a plastic molding operation is illustrated by Peden (N.A.C.A. Bul., vol. 20) as follows:

Labor (foreman and operating)	$ 3,969
Repairs	900
Supplies	3,000
Fixed charges	2,411
Apportioned general factory charges	2,520
Total cost	$12,800
Estimated hours	3,200
Hourly cost rate, plastic molding	$4.00

This **inclusive hourly rate** is used in determining the product cost.

Normal Burden

NORMAL CAPACITY DEFINED.—Normal capacity represents the average utilization of plant facilities required to meet the volume of sales orders over a period of years. By basing **overhead rates** on normal capacity, a rate results which stabilizes costs through periods of fluctuating production arising from seasonal and cyclical causes.

Normal Capacity Bases.—There are two general points of view regarding the method of determining normal capacity:

1. Normal capacity should be based entirely on ability of a plant to produce. This is potential operating capacity; also sometimes called practical capacity.
2. Normal capacity should be based on expected utilization of plant to meet expected sales over a period of years in the future. This is normal sales expectancy; it has also been called average capacity.

While the term "normal capacity" is applied to the results derived under both of these procedures, it is better to refer to "practical plant capacity" in the first case, and "capacity based on normal sales expectancy" in the second.

Capacity Relationships.—Fig. 16, by James (N.A.C.A. Bul., vol. 16), illustrates the major relationships involved. The maximum or **theoretical capacity** of a plant or department to produce would be that achieved under 100% operating time. This involves no limitation for waits and delays of any character, and is not achievable. In Fig. 16 it is represented by the line *AB*.

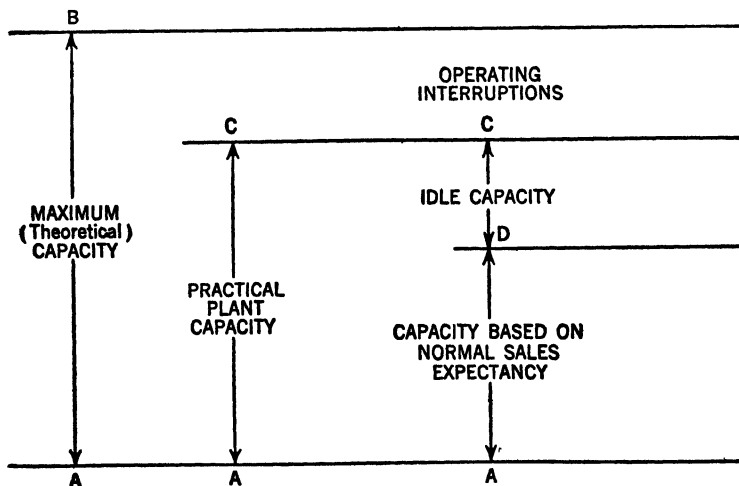



Fig. 16. Capacity Relationships

Practical plant capacity is maximum capacity less operating interruptions, and is shown by the line *AC* in Fig. 16. This represents practical utilization of the physical plant, without regard to commercial demands. Operating interruptions to be considered include, according to James (N.A.C.A. Bul., vol. 16): "Time lost for repairs, waits, breaks, set-ups, make-readies, clear-aways, machine failures, organization slips, unsatisfactory materials, delays in deliveries of raw materials from suppliers, labor fall-downs and absences." From the point of view of capacity to make, normal capacity is 75% to 85% of the theoretical maximum, depending on the nature of the industry and the circumstances surrounding the particular case.

Idle capacity (line *DC*, Fig. 16) is the unutilized portion of the plant and equipment, due to lack of customer demand. **Capacity based on sales expectancy** (line *AD*, Fig. 16) is measured by the productive equipment required to meet the average commercial needs over a period of time. On the chart this is the difference between practical operating capacity and idle capacity.

Units of Measurement of Plant Capacity.—Plant capacity may be measured in terms of:

1. Units of physical product.
2. Time of productive effort.
3. Dollars.

Where there is uniformity of product, it is convenient to express capacity in **physical units,** e.g., barrels of flour in a flour mill; tons of

MACHINE TOOL EXPENSE RATE

	Total	Standard	Excess
Fixed charges:			
Depreciation of machinery	$17.62		
Depreciation of building	.99		
Maintenance of machinery, equipment and building, real estate taxes, insurance, and watchmen	16.13		
Total weekly expense	$34.74		
Apportionment to standard cost: 72/120 of $34.74		$20.84	
Remainder to excess plant expense........			$13 90
Machine tool expense—hourly: $20.84 a week ÷ 54 normal hours a week		$ .40 approx.	
Power:			
101 D.C. 204 kw. at $.045 per kwh.........	.0918		
109 A.C. 230 kw. at .033 per kwh.........	.0759		
110 D.C. 255 kw. at .045 per kwh.........	.11475	.094 aver.	
Supervision and other overhead distributed on basis of standard productive hours....		.675	
Direct labor pay per standard productive hour		.54	
Standard processing cost per productive hour		$ 1.709	

FIG. 17. Normal Productive Hour Rate Including Direct Labor

rail in a rail mill; pounds of good castings in a foundry; pounds of wool in a woolen mill; tons of run-of-mine coal at the mouth of the shaft in a coal mine; gallons of pulp from beaters in a paper mill. Where there is a variety of product made from a diversity of raw materials, the **productive hour** serves as common denominator for measuring plant activity.

Thus assume that a group of three lathes has a maximum use of 120 hours a week, but that peak demand is 72 hours. This leaves 48 hours' excess capacity. The **normal burden rate,** as given by James (N.A.C.A. Bul., vol. 16), is then computed as shown in Fig. 17. The normal machine hour rate is stated as $.40 for fixed charges (actually, $20.84 ÷ 54 = $.386). This plus variable costs of $.769 (i.e., $.094 + $.675) gives a normal machine hour rate of $1.169. Adding in the rate for direct labor, there results a **standard processing cost** per hour.

Normal Capacity on Departmental Basis.—Where departmental burden rates are used, it is necessary to determine the normal capacity for each department in this plant. In general, there are two possibilities:

1. Set normal capacity for each department without regard to its relation to other departments in the plant.
2. Set the normal capacity of the "bottleneck" department, and relate all other departments to that normal. Under the latter approach, additional excess capacity costs are created in other departments. It is preferable to segregate and exclude them from normal rates.

Three-year tests in one factory disclosed that at full time operation actual output averages 80% of rated output. It would seem, therefore, that practical capacity for this plant would be 80% of **"bottleneck"** operation.

METHODS USED TO APPLY NORMAL OVERHEAD.—The generalized formula for computing a normal rate is:

$$\frac{\text{Budgeted overhead at normal capacity}}{\text{Normal production}} = \text{Normal burden rate}$$

Rates may be blanket, departmental, or by cost centers. The methods most frequently used to apply normal overhead in a standard cost system are:

1. Standard Direct Labor Dollar.
2. Standard Direct Labor Hour.
3. Standard Machine-Hour.

Other methods may be used, such as a **standard unit of product** basis. Also, a standard overhead rate may be combined with a standard rate for direct labor to obtain a **standard productive hour rate,** i.e., an inclusive rate for each cost center for direct labor and overhead.

The method of computing the rate for applying overhead on a normal basis and under each of the methods listed may be shown concisely by means of formulas:

1. $$\frac{\text{Overhead at normal capacity}}{\text{Standard amount of direct labor cost}} = \text{Standard percentage of direct labor cost}$$

2. $$\frac{\text{Overhead at normal capacity}}{\text{Standard number of direct labor hours}} = \text{Standard overhead per direct labor hour}$$

3. $\frac{\text{Overhead at normal capacity}}{\text{Standard number of machine-hours}} = \text{Standard overhead per machine-hour}$

Once the overhead at normal capacity is determined, it is only necessary to select the appropriate base to obtain a normal overhead rate.

DISPOSITION OF OVER- OR UNDERABSORBED NORMAL OVERHEAD.—A variety of practices exists regarding the disposition of under- and overabsorbed burden arising from the application of normal rates. The more important methods are:

1. Close out to **cost of sales.**
2. Adjust cost of sales and inventories on a pro-rata basis using the following formula:

   $\frac{\text{Overhead in work in process}}{\text{Total overhead applied during period}} \times \text{Total under- or overabsorbed overhead}$

   $= \text{Adjustment to work in process}$

   Similar computations are made for finished goods and cost of sales.
3. Close overabsorbed balances to a **reserve** whose function it is to absorb future underabsorption.

Specific Order Cost Systems

NATURE OF JOB ORDER SYSTEM.—A job or specific order system is one which collects separately each element of cost for each job or order worked on by the plant. This type of cost system is found in companies doing special work or manufacturing to order. Contractors, custom tailors, shipbuilders, machine shops, foundries, and ornamental metal work serve as illustrations; also plants which, though employing some other cost system for costing their products, use job order costs for special repair orders, research and development work, improvement and betterment orders, new machine installations, etc. The production of motion pictures falls in the class of job order costing, since each picture is a unique venture, and costs and profits must be determined for each picture.

Cost segregation by orders yields comparisons of costs and selling prices. It also furnishes a basis for cost estimates on similar work in the future. To accomplish this, a **job cost sheet** is set up for each job as soon as the order is issued.

FORMS REQUIRED FOR JOB ORDER SYSTEM.—For effective operations, job order production requires production control and accounting control. The two are difficult to separate since those charged with production depend in many instances on information contained in accounting records. In turn **computation of costs** depends in part on information gathered by the production section.

Forms most characteristic of, and most commonly associated with, specific order systems are:

1. Production order.
2. Bill of materials.
3. Operations schedule.
4. Planning or work-ahead schedule.
5. Move ticket or route card.
6. Cost sheet.

In addition some physical equipment is usually required, comprising a time clock for stamping starting and finishing time of jobs, and a production control board or suitable Gantt charts.

PRINCIPLES OF JOB ORDER COSTING.—Order numbers are assigned to all jobs or product lots for which costs are to be collected. A **cost sheet** (Fig. 18) is prepared for each order. To it are posted the actual costs of direct material, direct labor, and overhead at applied rates. The elements of manufacturing costs are thus brought together in one place. By dividing the total costs by the number of units produced, a unit cost is obtained.

A **Work in Process** control account of all jobs is maintained in the general ledger or the factory ledger. The cost of all work in process can be obtained by referring to this account if the cost records are kept up to date. The cost of any job in process at any time can be ascertained by referring to the cost sheet used to assemble costs for the job in question.

Charging Direct Material.—The sources of material postings are stores requisitions, bills of material, or move tickets issued when mate-

INVOICE NO.______ **COST SHEET** JOB NO.______

MATERIAL						SHOP ORDER EXPENSE					
Date	Issue Number	Amount	Date	Issue Number	Amount	Date	Charge Number	Amount	Date	Charge Number	Amount

	OPERATION	Shop No.	Hours	Amount
1	Layout and Preparation	V		
5	Pipe—Angle—Bands	V		
4	Welders	V		
3	Blacksmiths	V		
2	Machine Shop	V		
6	Polishers	V		
7	Platers	V		
16	Inspectors & Movemen	V		
15	Painters—Finishers	V		
12	Heavy Sheet Metal	VI		
11	Range Shop	VII		
13	Counter Shop	VIII		
9	Tin Shop	IX		
10	Urn Shop	IX		
8	Copper Shop	IX		
14	Misc. Repair Shop	IX		
17	Specialty Shop	X		

ESTIMATED			ACTUAL		
Shop	Hours	Amount	Shop	Hours	Amount
V			V		
VI			VI		
VII			VII		
VIII			VIII		
IX			IX		
X			X		
Labor			Labor		
OVHD			OVHD		
Material			Material		
Total			Total		
Estimated Unit Cost			Variance From Estimate		
Actual Unit Cost			Predetermined Billing		
Signed Out		Approved	Variance From Billing		

FIG. 18. Job Order Cost Sheet

rials are moved from storeroom to factory. After posting of issues to stores ledgers has been completed, the requisitions are sorted daily by order numbers, and posted to their respective cost sheets. From a summary of stores issued, suitable Work in Process controls are charged. Scrap and spoilage may be credited back on the cost sheets. Repairs to product judged defective constitute part of the departmental overhead, and should not ordinarily appear as a job cost.

Charging Direct Labor.—Time tickets form the basis of labor charges to the cost sheets. These tickets must be so designed as to show labor hours and the cost on each job worked on by the departments. After the tickets have served their purpose in the payroll department, they are turned over to the cost department. The latter analyzes the tickets according to direct and indirect labor by operations and departments. The results of the analysis are recorded on a **labor distribution sheet.** Direct labor time tickets are then sorted by production order numbers and posted to cost sheets. Control over postings is obtained by accumulating daily analyses on a monthly **recapitulation sheet** which forms the basis for a charge to Work in Process.

Charging Manufacturing Overhead.—Under job order procedure, expenses are applied to production by means of overhead rates. Such rates may be calculated at the end of the month on the basis of expenses actually incurred, or they may be predetermined on the basis of estimated future expenses. The cost clerk computes the overhead cost to be charged to the order and posts the amount to the cost sheet. If only actual costs are desired, the cost sheets are corrected by use of a **supplementary overhead rate** (see page 1449), or else rates based on actual expenses incurred are employed. From a summary of such overhead amounts, a journal voucher is prepared charging Work in Process.

SPECIFIC CHARGES.—Costs often charged to a given order consist of such items which were specifically incurred for that order and whose benefits are not expected to last beyond the completion of the order. Special experimental and other engineering expenses, use of special tools, dies, etc., are legitimate charges to job costs.

All such direct charges must be evidenced by proper **vouchers** authorizing the charges to the respective job cost sheets and eventually to Work in Process.

VALUING WORK IN PROCESS.—The value of work in process is made up of material, labor, and burden through the stage of completion reached at the closing date. Therefore all material requisitions, time tickets, and vouchers representing direct job charges must be posted at the end of the cost period. In addition, overhead must be ascertained and posted. In this way, the live cost cards constitute a book inventory of work in process.

When jobs are completed, they are turned over to finished stock or to the shipping department. The cost sheets are closed, and costs are transferred to Finished Goods or Cost of Sales on the basis of a summary of completed production orders. The balance in Work in Process represents the closing inventory.

FINANCIAL STATEMENTS AND OTHER SUMMARIES.—The financial statements under a job order system are no different from

statements prepared under other cost systems. From the accounts there are prepared:

1. Profit and Loss Statement, supported by,
   a. Statement of Cost Production.
   b. Statement of Cost of Sales.
   c. Selling Expenses, Administrative Expenses.
   d. Nonoperating Expense and Income Statements.
2. Balance Sheet, supported by such schedules as are deemed necessary, including a Surplus Statement.

Cost reports in job order plants cover such items as individual job cost sheets (particularly on orders involving heavy expenditures of time and money), summary cost sheets, production center costs, defective work reports, costs by lines of product, etc.

Continuous Process Cost Systems

PROCESS COSTS DEFINED.—Process costing represents a type of cost procedure for continuous or mass production industries. In such industries output consists of like units, each unit being processed in like manner. Therefore, it is assumed that the same amount of material, labor, and overhead is chargeable to each unit processed. As stated by Newlove and Garner (Elementary Cost Accounting): "When reduced to its barest essentials, process cost accounting is the procedure by which unit product costs are obtained through the application of some type of averaging technique."

In process costing, the terms process and department are used interchangeably. In order that costs may be accumulated on a process basis, it is necessary to departmentalize the plant and to indicate the limitations of each department or cost center.

PROCESS COST PROCEDURE.—Where production is continuous, special production orders are not required. This is the case in ice plants, mining, quarrying, steam plants, etc., and involves planning of the work so that continuity of production is maintained. Starting with the sales budget and making allowance for seasonal variations, returns, inventories, etc., production quotas are set by months or other convenient time interval. Notice of these quotas is given to the production control section, which in turn transmits them to the producing centers.

Blocker (Cost Accounting) lists the following steps in process cost accounting:

1. Costs, both direct and indirect, are accumulated in expense accounts during the period and are **reclassified by departments** or processes at the end of the period.
2. Production in terms of **quantities**, such as units, tons, pounds, feet, and gallons, are recorded by processes daily or weekly and are summarized in **departmental reports** at the end of the period.
3. The total cost of each process is divided by the total production for the process to obtain an **average cost** per unit for the period.
4. When products remain in process at the end of a period, production and inventories are computed in terms of **completed products**, the stage of completion usually being estimated and the identity of each lot being ignored.

5. If units are lost or spoiled in a department, the loss is borne by the units completed and remaining within the department, thus increasing the average cost per unit.
6. In cases where products are processed in more than one department, costs of one department are transferred to the next department, the total cost and unit cost of products being accumulated when completed.

PRODUCTION RECORDS.—Records of quantities are intended to measure the flow of product through the plant from the time of the receipt of new material to the time of final shipment. Daily production reports are compiled. These keep management informed of actual achievements with respect to scheduled production quotas, and furnish one of the necessary elements in cost computations by the cost department.

MATERIAL COST.—Material costing involves the use of perpetual inventory controls. Emphasis is, however, on providing means for charging materials to the proper **process** and **product** at the time of consumption. Quite often material requisitions may be dispensed with, and so-called **consumption reports** substituted. These reports may be prepared in two ways:

1. By formula.
2. By proration.

Consumption Reports by Formula.—In continuous process plants it is often impracticable to use material requisitions, since raw materials flow into the process in a steady stream. It is sometimes possible, however, to tell how much material was consumed in production from a knowledge of the quantity of finished product produced. Consumption reports by formula are particularly useful in connection with **standard costs** since the formulas then become standards. They are used in bakeries, plate glass manufacture, in fact, wherever standard mixtures are the basis of a manufacturing process.

Prorated Material Costs.—Sometimes material costs are prorated to the product on the basis of some physical coefficient, such as tonnage, etc. In Fig. 19 the cost per pound is determined by dividing the raw material cost of $20,000 by the total poundage, and using the resulting unit cost as a basis for charging the material cost to each product. Proration, however, tends to produce inaccuracies in unit product costs due to variations in waste and spoilage on different runs.

	Total	Product A	Product B	Product C
No. of units produced....	10,000	4,000	5,000	1,000
Average weight per unit..	1.6 lb.	1.25 lb.	1.4 lb.	4 lb.
Total pounds produced...	16,000 lb.	5,000 lb.	7,000 lb.	4,000 lb.
Material cost per pound..	$1.25	$1.25	$1.25	$1.25
Raw material proration..	$20,000	$6,250	$8,750	$5,000
Material cost per unit....	$2.00	$1.5625	$1.75	$5.00

Fig. 19. Proration of Raw Material Costs

DIRECT LABOR COST.—The essential requirement is to analyze labor by processes. Analysis is accomplished by sorting the daily **time tickets** according to subclassifications:

1. For direct and indirect labor.
2. By processes and service departments.

At the end of the month, a **labor distribution sheet** is prepared showing all labor applicable to the operations of the month. This serves as a basis for charging each process for its share of direct and indirect labor.

MANUFACTURING EXPENSE.—Manufacturing expense under a process cost system is collected, distributed, and applied to the product in the same manner as under any other system. If only one product is manufactured, all actual expenses, analyzed by processes, are automatically charged to it. Examples of this type of overhead charging are found in baking industry, breweries, sulphur mining, coal mining, etc.

Where several products are produced simultaneously or in successive runs, overhead may be charged to products by:

1. Apportioning on some convenient basis the actual expenses within each process to the products worked on.
2. Use of predetermined departmental expense rates.

ANALYSIS OF MANUFACTURING COSTS.—The work of cost analysis is facilitated by use of a distribution sheet. Accounts are listed down the page, producing and service departments across the page. This is similar to an expense distribution sheet, but in process costing all elements of cost are included since they constitute direct charges to the product and are not broken up by job orders. In effect this becomes a **cost sheet** for the product.

Gillespie (Introductory Cost Accounting) shows a form of distribution sheet (Fig. 20) which serves as a means of accumulating and distributing factory expense, and transferring process costs.

Where inclusion of raw material and direct labor is inadvisable, the process distribution sheet becomes an **expense distribution sheet** and is handled in the usual manner.

UNIT COSTS BASED ON EFFECTIVE PRODUCTION.—In its simplest form a unit product cost is determined for each process on the basis of material, labor, and overhead incurred in that process for a given production. However, the existence of **work in process** at the beginning or end of the period necessitates a refinement of the above method of costing. Since a part of the cost incurred applies to units still in process, the total cost cannot be charged to units finished or transferred to another department for further processing. Costs must be spread over all the work of the department.

To spread the total costs over all work done in a department, the work of the department must be expressed in terms of a common denominator, referred to as the effective production. The latter, sometimes called **equivalent production**, represents the total work of a department or process in terms of **fully completed units.** This idea rests on the assumption that the work in producing 100 units of product one-half completed is equivalent to 50 units fully completed.

FEDERAL CEMENT MILLS

PROCESS COST SHEET - MONTH OF JANUARY, 19__

	Mill Overhead	Power, Light & Water	Machine Shop	Coal Preparing Per Ton	Coal Preparing Amount	Raw Grinding Per bbl.	Raw Grinding Amount	Clinker Burning Per bbl.	Clinker Burning Amount	Clinker Grinding Per bbl.	Clinker Grinding Amount	Finished Goods	Totals - Credit Labor, Expense & Materials
Production	-	-	-	4,000 tons	-	28,000 bbls.	-	28,000 bbls.	-	26,000 bbls.	-	-	-
Current Charges:													
(1) Labor	$348.80	$ 985.93	$2,400.00	$ -	$ 248.67	$ -	$ 2,588.00	$ -	$ 1,099.20	$ -	$ 3,834.08	$ -	$11,504.68
(2) Supplies	40.00	320.00	40.00	-	240.00	-	200.00	-	180.00	-	140.00	-	1,160.00
(3) Repair Materials	-	280.00	16.00	-	200.00	-	312.00	-	520.00	-	316.00	-	1,644.00
(4) Coal	-	3,200.00	60 00	-	6,000.00	-	180.00	-	-	-	-	-	9,440.00
(5) Depreciation	-	300.00	66.67	-	93.33	-	680.00	-	960.00	-	1,000.00	-	3,100.00
(6) Taxes	-	35.00	6.00	-	5.00	-	60.00	-	94.40	-	110.00	-	310.40
(7) Insurance	8.20	47.20	48.20	-	6.00	-	60.00	-	26.40	-	49.92	-	240.92
	$392.00	-	-	-	-	-	-	-	-	-	-	-	-
Service Charges:													
(8) Mill Overhead	392.00*	30.00	120.00	-	12.00	-	120.00	-	80.00	-	30.00	-	-
		$5,198.13	-	-	-	-	-	-	-	-	-	-	-
(9) Power, Light & Water		5,198.13*	80 00	-	18.13	-	2,080.00	-	1,920.00	-	1,100.00	-	-
			$2,836.87	-	-	-	-	-	-	-	-	-	-
(10) Machine Shop			2,836.87*	-	176.87	-	720.00	-	720.00	-	1,220.00	-	-
(11) Conversion Cost, by departments				-	$7,000.00	-	$ 7,000.00	-	$ 5,600.00	-	$ 7,800.00	-	-
(12) Unit Conversion Cost				1.75	-	.25	-	.20	-	.30	-	-	-
Transfer Charges:													
Materials -													
(13) Lime to Raw Grinding					-	.11+	3,200.00	-	-	-	-	-	3,200.00
(14) Clay to Raw Grinding					-	.03+	960.00	-	-	-	-	-	960.00
(15) Gypsum to Clinker Grinding					-	-	-	-	-	.06+	1,680.00	-	1,680.00
Inter-Department -													
(16) Prepared Coal to Clinker Burning					7,000 00*	-	-	.25	7,000.00	-	-	-	-
						$ .39+	$11,160.00	-	-	-	-	-	-
(17) Ground Materials to Clinker Burning						.39+	11,160.00*	.39+	11,160.00	-	-	-	-
								$ .84+	$23,760.00	-	-	-	-
(18) Clinkers to Clinker Burning								.84+	23,760.00*	.91+	23,760.00	-	-
										$1.27+	$33,240.00	-	-
(19) Cement to Warehouse											33,240.00*	33,240.00	-
												$33,240.00	$33,240.00

-* Red.

Fig. 20. Combined Distribution and Cost Sheet

STEPS IN COMPUTING PROCESS COSTS.—In computing process costs, the following steps must be taken:

1. Compute effective production from given data.
2. Calculate net conversion or net process cost.
3. Compute unit conversion or unit process cost (item 2 divided by item 1).
4. Credit process account for value of closing Work-in-Process Inventory on the basis of:
   a. Unit conversion or unit process cost taking into account stage of completion.
   b. Full transferred unit cost.
5. Balance of process account represents charge to be transferred to the next process or to Finished Goods.

The problem below is adapted from Amidon and Lang (Essentials of Cost Accounting) and illustrates the computation of the effective production, steps in computing process costs, and the transfer of process costs. It is based on the following data.

Charges to process accounts:

	Dept. A	Dept. B
Inventory at beginning	$ 250	$1,430
Material	8,000	—
Labor	4,000	5,000
Expense	2,900	2,000

Production data:

	Dept. A		Dept. B	
	Number of Units	Stage of Completion	Number of Units	Stage of Completion
Opening Inventory:				
Material	500	30%		
Labor		50	1,000	70%
Expense		50		70
Put into Process	15,000		12,500	
Completed and forwarded to next department	12,500		13,000	
Closing Inventory:				
Material	3,000	100		
Labor		40	500	80
Expense		40		80

No new material is added in process B. Below are presented the working papers and a process cost report (Fig. 21a and 21b).

PROCESS COST STATEMENTS.—An important feature of process cost statements is the ease with which comparative reports may be prepared. In industries where operations are repetitive and continuous, unit costs ought to exhibit a high degree of stability. **Variations**

in costs are an indication of the presence of factors out of the ordinary. In other words, cost variations are looked for and the reasons for the variations are investigated. In this connection, process cost accounting permits easy computation of costs as often as desired. The frequency of computation depends on the type of industry, particularly on the rapidity of **inventory turnover**, or on the length of a **manufacturing cycle.**

Where there are no process inventories or where a manufacturing cycle is completed in 24 hours, **daily reports** are the rule. This is the case in bake shops, dairies, etc.

Monthly Profit and Loss Statements.—In general, the monthly operating statements depend on the nature of the industry, size of plant, and the degree to which management is aware of a need for cost reports and statistics in controlling operations. In process cost plants, departmental **production cost analysis** is usually the first and most basic report prepared. It is a direct outgrowth of the departmental unit cost computations, valuation of transfers, inventories in process, spoilage, etc. The statements themselves may be very simple or become very complex depending on:

1. Number of products manufactured.
2. Extent of subclassifications desired:
   a. By products.
   b. By elements of cost.
   c. By departments or processes.
   d. Or by any combination of the above.

Periodic statements are also prepared. These consist of the usual balance sheet and profit and loss statement.

	Physical Units	Material		Labor and Expense	
		% Incomplete	Equivalent Units	% Incomplete	Units
Process A:					
Opening Inventory	500	70%	350	50%	250
Put into Process	15,000		15,000		15,000
Total Incompleted Units Handled	15,500		15,350		15,250
Less Inventory at end	3,000	0	—	60	1,800
Effective Production	12,500		15,350		13,450
Process B:					
Opening Inventory	1,000	0	—	30	300
Put into Process	12,500				12,500
Total Incompleted Units Handled	13,500				12,800
Less Inventory at end	500	0	—	20	100
Effective Production	13,000				12,700

Fig. 21a. Computation of Effective Production

Cost of Production

	Department A				Department B			
	Effective Quantity	Physical Quantity	Total Cost	Unit Cost	Effective Quantity	Physical Quantity	Total Cost	Unit Cost
1. Opening Inventory per ledger accounts		500	$ 250 00			1,000	$ 1,430.00	
2. Received from prior department						12,500	12,970.86	$1.037669
3. Current Costs:								
Material........................	15,350	15,000	8,000 00	$ .521173				
Labor..........................	13,450		4,000 00	.297398	12,700		5,000.00	.393701
Expense.	13,450		2,900.00	.215613	12,700		2,000.00	.157480
Total Conversion Cost...........	13,450		6,900.00	.513011	12,700		7,000 00	.551181
4. Total Process Charges...............		15,500	15,150 00			13,500	21,400.86	
5. Less Inventory at end (See Schedule below).		3,000	2,179.14			500	739.30	
6. Cost of Goods Transferred...........		12,500	$12,970.86	$1.037669		13,000	$20,661.56	$1.589351

Schedule of Closing Inventory Values

Department A:

Materials	(3,000 × $ .521173)	$ 1,563.52
Labor	(3,000 × 40% × $ .297398)	356.88
Expense	(3,000 × 40% × $ .215613)	258.74
Total Inventory	....	$ 2,179.14

Department B:

Material	....	$ —
Labor	(500 × 80% × $ .393701)	157.48
Expense	(500 × 80% × $ .157480)	62.99
Prior Cost	(500 × 100% × $1.037669)	518.83
Total Inventory	....	$ 739.30

Fig. 21b. Process Cost Report and Inventory Schedule

Joint and Byproduct Costs

DEFINITIONS.—Byproducts are products recovered from material discarded in a main process, or from the production of some major product, where the material value is to be considered at the time of severance from the main product. White (Journal of Accountancy, vol. 51) defines the term as "any salable or usable value incidentally produced in addition to the main product." These definitions emphasize byproducts in terms of **recoverable values** from waste material resulting from manufacturing operations.

Joint products represent two or more products separated in the course of the same processing operations, usually requiring further processing, each product being in such proportion that no single product can be designated as a major product.

METHODS OF BYPRODUCT ACCOUNTING.—There are several generally accepted methods of accounting for byproducts:

1. Net sales of byproducts treated as "Other Income" on profit and loss statement.
2. Total sales less total costs.
3. Total cost less value of byproducts.

Other Income Method.—In this cost procedure, income arising from the sale of byproducts may be recorded in a special account and shown as secondary income on the profit and loss statement. An illustration follows:

Sales of main product (1,000 units at $10)		$10,000
Cost of sales:		
Produced (1,200 units at $8)	$9,600	
Less inventory of main product (200 units at cost, 1/6 of production cost)	1,600	8,000
Gross profit		$ 2,000
Selling and administration expense		500
Operating income		$ 1,500
Other income:		
Byproduct sales (1,000 units at $.60)		600
Income for period		$ 2,100

Total Sales Less Total Costs.—Under this method, costs of all products are subtracted from sales of all products, as follows:

Sales of all products:		
1,000 units main product at $10	$10,000	
1,000 units byproduct at $.60	600	$10,600
Cost of sales (as in first illustration)		8,000
Gross profit		$ 2,600
Selling and administrative expense		500
Net income for period		$ 2,100

Total Cost Less Revenue from Byproducts.—This method produces a number of variants. Under the first, all costs are charged to the main product whose cost is then reduced by the revenue from the byproduct or by the market value of the byproduct. An illustration by Sheppard (N.A.C.A. Bul., vol. 4) follows:

Coal (1,000 tons at $4 per ton)		$4,000
Byproducts recoverable:		
Tar (12,000 gals. at $.05 per gal.)	$ 600	
Sulphate of ammonia (26,000 lbs. at $.02½ per lb.)	650	
Gas (7,000,000 cu. ft. at $.15 per thousand cu. ft.)	1,050	
Benzol extraction (3,000 gals. at $.20 per gal.)	600	
Total value byproducts recoverable		2,900
Coke material cost		$1,100
Carbonizing costs (1,000 tons at $1 per ton)		1,000
Furnace coke (660 tons at $3.18 per ton)		$2,100

A second variant includes an allowance for selling and administrative expense in the deduction of the byproduct from total costs. A third method deducts the **net yield** of byproducts from the total costs of the main product. That is, the revenue from byproducts is charged for costs subsequent to the **split-off point.**

Finally, byproduct values may be deducted from total costs at a standard cost. Although this stabilizes the byproduct values, it throws cost fluctuations on the main product with added emphasis.

METHODS OF JOINT PRODUCT ACCOUNTING.—By definition, each joint product is of equal importance; hence, management must try to secure a profit on each one. To do this, joint costs must be prorated and subsequent costs properly charged. Generally speaking, there are three basic methods of accounting for joint product costs up to the split-off point:

1. Average unit cost, as in process cost accounting.
2. Apportionment on the basis of some physical unit, such as weight, volume, linear measure, atomic weight, heat units, etc.
3. Apportionment on the basis of the relative market values of the finished products.

None of the above methods is thoroughly satisfactory; at any rate, not in all cases. On the whole, the first and second methods mentioned above, in spite of their apparent lack of any scientific attempt to solve the problem of joint costs, are about as satisfactory as any. Certainly, they are the simplest in operation.

An example taken from the operations of a sawmill illustrates the method of apportionment on a **unit cost** basis:

1. Total production	2,500,000 ft.
2. Total cost (joint)	$53,000.00
3. Average cost per 1,000 ft., (1) ÷ (2)	$ 21.20

This average is used to cost the various grades produced in proportion to their quantities:

Grades	Quantities Produced (ft.)	Average Cost per 1,000 ft.	Value of Product
First and seconds	250,000	$21.20	$ 5,300.00
No. 1 common	1,250,000	21.20	26,500.00
No. 2 common	500,000	21.20	10,600.00
No. 3 common	500,000	21.20	10,600.00
	2,500,000		$53,000.00

The method has been sanctioned by the Bureau of Internal Revenue. Using the same example of lumber mill costs used for the average unit cost proration, the joint cost of $53,000 is distributed to the various grades on the basis of their **market values** as follows:

JOINT COST APPORTIONMENT ON MARKET VALUE BASIS (LUMBER MILL)

Grades	Quantity Produced (ft.)	Market Value per 1,000 ft.	Total Market Value	% of Total Market Value	Prorated Cost	Cost per 1,000 ft.
First and seconds	250,000	$105.00	$ 26,250	17.65	$ 9,354.50	$37.42
No. 1 common...	1,250,000	70.00	87,500	58.82	31,174.60	24.94
No. 2 common...	500,000	40.00	20,000	13.45	7,128.50	14.26
No. 3 common...	500,000	30.00	15,000	10.08	5,342.40	10.68
	2,500,000		$148,750	100.00	$53,000.00	

Sheppard (N.A.C.A. Bul., vol. 4) presents an illustration of prorating the joint cost on a weight basis in the manufacture of coke. The weights of all the finished products are determined, per ton of coal, with the exception of gas, which may be found by subtracting the totals of the other products from 2,000.

Assuming one ton of coal to cost $4, the following schedule results, showing the apportionment of weight and material cost to each product, the apportionment being made in the ratio that each product weight bears to the total product weight:

SCHEDULE SHOWING APPORTIONMENT OF MATERIAL COST VALUE TO EACH PRODUCT PER TON OF COAL

	Yield in Lbs. of Recovered Products per Ton of Coal	Distribution of Waste to Recovered Products (lbs.)	Revised Weight of Recovered Products	Material Cost of Each Product on Basis of Weight
Coke	1,320.0	69.47	1,389.47	$2.78
Coal tar	120.0	6.32	126.32	.25
Benzol	21.9	1.15	23.05	.045
Sulphate of ammonia.	26.0	1.37	27.37	.055
Gas	412.1	21.69	433.79	.87
Waste (water)	100.0			
Total	2,000.0	100.00	2,000.00	$4.00

Setting Standard Costs

STANDARD COSTS DEFINED.—Standard costs are **predetermined** costs established by a process of scientific fact finding which utilizes both past experience and controlled experiment. Thus the process of setting standard costs generally includes:

1. A careful selection of materials.
2. Time and motion studies of operations.
3. An engineering study of equipment and other manufacturing facilities.

When introduced into the accounting records, the standard cost plan compares actual costs against the standards, and analyzes any variance between the two as to causes.

TYPES OF STANDARD COSTS.—There are two fundamental types of standard costs:

1. Current or attainable standards.
2. Basic or measurement standards.

Current Standards.—A current standard is one which is intended to be representative of what a cost should be under prevailing circumstances. It is generally regarded as a real cost to be carried through the books of account and into the financial statements. Such standards must be revised frequently to reflect changes in methods and prices, for otherwise they cease to be representative costs.

Basic Standards.—A basic standard is intended to serve only as a yardstick with which both expected and actual performance can be compared. While possessing some of the characteristics of standard weights and measures, it is more nearly analogous to the base upon which a price index number is computed, for the plan of cost accounting used with this type of standard proceeds by reducing actual costs to **percentage relatives** with standard cost as a base. Unlike current standard costs, basic standard costs are used along with actual costs in the ledgers and financial statements. One important characteristic of basic standards is that they facilitate showing of trends in current costs relative to the basic standard cost. Such calculations require that the base upon which ratios are computed shall remain fixed and hence basic standard costs are changed only when methods of manufacturing are altered.

Relation of Basic to Current Standards.—When basic standards are applied, it is necessary to use current standards also, but current standards can be used without basic standards. The reason for this is that a basic standard by itself does not necessarily represent what the performance ought to be in given period, but serves only as a base from which to measure changes. Hence, when a system of basic standard costs is used, the following rules govern:

1. Current standards are determined and expressed as percentages of the corresponding basic standard figures.
2. Actual costs, likewise expressed as percentages of the basic standard, are then compared with the current standard to find out how much actual performance has deviated from what it should have been, and with the basic standard to determine trends from period to period. This latter comparison would not, of course, be possible by measuring changes from a shifting current standard.

DIRECT MATERIAL STANDARDS.—Establishment of a standard cost system presupposes the existence of adequate physical control over the processes of procuring, storing, issuing, and handling of materials from the time a request to purchase is initiated until the finished goods are shipped to a customer.

The setting of direct material standards involves specifications as to:

1. Kind and quality of materials.
2. Quantities required.
3. Prices.

The first two are largely engineering problems, the last is the joint responsibility of the purchasing department and cost accountant.

Material Kind and Quality Specifications.—These are known as **material usage** standards and involve a determination of what is the best and most economical material to use for each purpose. If no scientific study of materials has ever been made, a careful engineering investigation should be a preliminary step to setting satisfactory standard costs. Raw material inventories can be materially reduced if the engineering department prepares **standard material lists** which can be used by designers in development of new parts and products. Additions to such lists should be prohibited unless approved by the chief engineer.

Material Quantity Specifications.—These take the form of standard usage specifications, showing standard quantities to be consumed in each manufacturing operation. Where the manufacturing process is complex and involves manufacturing of parts and their assembly later, perhaps in several stages, it is desirable to have a separate set of usage specifications for each stage, beginning with a standard list for each part, other lists for each subassembly, and finally still other lists for each final assembly. These specifications are often supplemented by **drawings.** Such a drawing provides a description of the part; states part number or symbol used for identification; specifies kind of material to be used; and specifies all labor operations necessary to convert raw material to finished part. The drawings may be further supplemented by **route sheets.** These serve the dual purpose of setting up a permanent record of required processing, together with a record of tools needed; and also, when job number and quantity have been inserted, they may be used as **production orders.**

Standard for Shrinkage, Scrap, and Waste.—When loss takes place while materials are in stores (from leakage, evaporation, deterioration, etc.), the price at which materials are charged out to material in process may be raised enough to cover the amount of the loss or an expense account may be charged. On the other hand, losses occurring while material is in process must be compensated for by increasing the **usage standard.**

Record of Excess Material Usage.—When material in excess of the standard quantity allowed is withdrawn, a so-called **excess material requisition** may be required. This immediately brings to the attention of the foreman the fact that his production center is incurring an unfavorable cost variation and may stimulate him to seek a way to save material.

When adequate material usage standards are in effect, control over material losses, wastes, and spoilages is facilitated because any variance from what has been determined to be a proper figure can be traced to its source. If it is due to faulty equipment, this can be repaired; if due to careless or improper use, pressure can be brought to bear upon the person responsible; or if due to causes over which the company lacks control (such as inability to obtain the proper grade of materials or the lack of skilled workers), the amount of loss from such conditions is at least pointed out in clear fashion.

Material Price Standards.—Setting of material price standards calls for fixing a standard unit cost for each kind of material used; the result is a list or catalog of standard material prices. Pricing the standard

material specifications depends on the nature of the standard to be used. Many concerns contract for their materials considerably in advance of the time when they are to be used, and the contract price becomes standard material cost. In other cases it is customary to carry very large stocks of raw materials and here the price actually paid is available as the standard cost.

If the standard calls for **normal costs,** the process of setting standard prices requires a statistical determination of the normal price level. The setting of price standards involves an element of individual judgment, for the best price forecasting or best normal prices that current techniques can produce have proved to have a wide margin of error. This fact does not vitiate standards, however, for they still can serve as a check upon efforts of the purchasing department and as a readily available estimate of excess material prices.

The level at which price standards are set under the **basic type** of standard is not important, so long as price is not too far from reality. Prices current at the time the standard is set or prices which are thought to represent normal conditions may be taken for the purpose. The material element in inventories is priced at actual cost by the plan of bookkeeping used with basic standards and hence no question is involved of the effect the standard price will have on the balance sheet.

DIRECT LABOR STANDARDS.—The setting of direct labor standards includes standardization of all surrounding conditions that in any way influence the effectiveness with which the worker performs his task:

1. Consideration of layout, conditions of equipment, the workplace, and transportation facilities to standardize these at the best practicable level under existing circumstances.
2. Establishment of control over materials in order that the workman may have the correct quality and quantity available at the proper workbench or machine.
3. Development of a system for planning, routing, and dispatching of work.
4. Provision of all needed instructions for the worker, either in the form of advance training or directions for each specific job.

Since standard costs are thus based upon methods and conditions which it is desired to attain, variations of actual from standard then become indicative of real **variations in efficiency** relative to the standards.

Setting Standard Operation Times.—Many companies already have available complete operation time standards developed for purposes of wage payment and planning of production. These are exactly what is needed as a basis for the labor usage element in standard labor costs. Where operation times are not already at hand, standard operation times should be set by one of the following methods:

1. Time and motion study.
2. Average of past performance.
3. Advance estimate.

In some circumstances it is feasible to develop **empirical formulas,** schedules, tables, or curves from which standards can be set for operations not previously performed.

Setting Labor Rate Standards.—Since there is usually considerable variation in rates paid for labor, the first step should be establishment of a **classification of labor grades** used. This should comprise a definite set of specifications for each grade in order that grades may be clearly distinguishable. The aim here is to set up a logical basis for differentials in wage rates paid, and to make possible specification of the particular grade of labor that is to be used for each operation in the plant.

The next step is setting of **standard rates of pay** for each of these grades of labor. In this, the procedure is influenced by the circumstances under which labor is hired. If a plant operates under contract with a labor union, the rates paid workers are fixed by the terms of the contract. In such a case the contract rates form the standard rates. If wages are established by bargaining individually with employees, the prevailing market rate for similar types of work is an important consideration, although it cannot be the sole guide. Most important, perhaps, is the establishment of a rate which fairly represents the qualifications of the job relative to other jobs in the plant.

MANUFACTURING EXPENSE STANDARDS.—The fundamental aim of overhead standards is to facilitate localization of expenses for cost control. This requires, as a first step toward establishing overhead standards, an analysis of expenses by departments and cost centers. The next step is the separation of **fixed** and **variable expenses.** Unless these two kinds of overhead are separated, it is impossible to determine whether an increase in unit cost is due to an unavoidable increase in unit fixed cost or to failure to control the total variable costs. It also

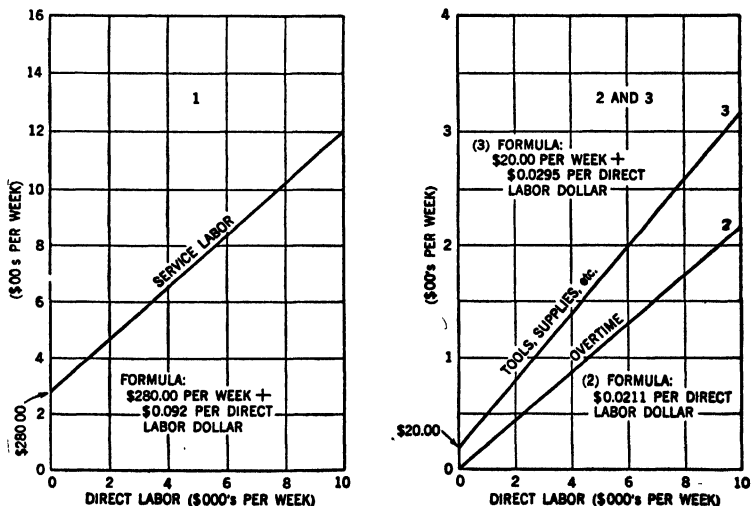



Fig. 22. Deriving Formula from Graphic Analysis of Fixed and Variable Components for Indirect Labor

becomes difficult to place responsibility for increases in costs when costs charged to a given department contain **prorated fixed charges** unless these fixed charges are clearly separated from the variable costs subject to control by the department charged.

The standard overhead may be represented by chart or formula (Fig. 22), or again by a flexible budget. In Fig. 22, taken from Martin (N.A.C.A. Bul., vol. 20), the vertical axis shows the expense, the horizontal axis the direct labor. The chart readings may be reduced to a **formula,** by noting the constant factor, that is, the **stand-by cost** at zero operation, and then noting the rate of change per unit. This produces the following formulas:

1. For service labor:
   $280 per week + $.092 per direct labor dollar
2. For overtime:
   $.0211 per direct labor dollar
3. For tools, etc.:
   $20 per week + $.0295 per direct labor dollar

There is no **stand-by charge** in the case of overtime, since obviously overtime disappears at zero operation. To obtain the formula for service labor proceed as follows:

1.	Stand-by charge (zero operation)	$ 280
2.	Charge when direct labor is $10,000 (from chart)	1,200
3.	Difference in service labor readings	$ 920
4.	Difference in direct labor readings	$10,000
5.	Ratio of item 3 to item 4:	

$$\frac{\$920}{\$10,000} = .092$$

or 9.2 cents per direct labor dollar

To find the allowed expense at, for example, $6,200 of direct labor, proceed as follows:

$$\$280 + (\$6,200 \times .092) = \$280 + \$570 = \$850$$

This checks with the graph in Fig. 22.

Use of a curve or formula provides automatically the allowed expense at any activity level within the expressed range. If a schedule is used, it must set forth the allowable expense at specified points of activity. Such a schedule of standard or allowable expenses at various levels is called a **flexible budget.**

RESPONSIBILITY FOR SETTING STANDARD COSTS.—When costs are classified according to personal authority over spending, responsibility for each item can then be definitely assigned to a specific person, a standard can be established, and that person held accountable for variances arising from any failure to meet the standard. In general, authority and responsibility for cost control follow organization lines and an **organization chart** is a useful guide in classifying overhead costs.

Standards Committee.—The general direction and supervision of a standardization program is commonly delegated to a division or committee created for the purpose. Such a body continues in existence after the initial establishment of standards to aid in their effective application and to make changes that are necessary as new circumstances render previous standards obsolete.

Responsibility of Foremen.—Standards are sometimes reviewed by the persons held responsible for their maintenance before being put into effect. Thus, in connection with Fig. 23 Perry (N.A.C.A. Bul., vol. 22), states:

After eliminating **variations** due to volume and management, those which remain are attributable to the foreman. On direct material and labor any variations due to prices or rates have been eliminated, so that any variance on these items is due to inefficient usage. Burden variances charged to the foremen are those which result from not following budget standards. The amounts shown in the last column as the foreman's budget for the month are the standard costs, adjusted for variations due to the level of operation and variations caused by management.

Responsibility of Management.—General management, as distinct from the departmental operating executives, must assume its share of responsibility. Thus, speaking of the results in Fig. 23, Perry, cited above, states:

The variations charged to management are those which occur due to changes over which the foreman has no control, such as, in this case, a 10% wage increase. It is this column which provides the flexibility necessary to keep the foreman's budgets right up to date, for it absorbs any variations caused by management changes since the standards were set. This column also keeps the executives informed as to the cost of the changes which they have instituted.

REVISION OF STANDARDS.—Current standard costs must be changed when prices, manufacturing methods, product specifications, or other circumstances change to such an extent that the standard no longer represents a good measure of performance. It is also necessary to change **current standards** which are found to have been incorrectly set. This should be done only when the existing standard is clearly erroneous, for the objective of standards is defeated if management does not resist any tendency to lower standards rather than to raise performance. Many concerns review all standard costs once a year and make changes at that time.

Basic standard costs are revised only when methods of manufacturing change or when plant capacity changes, or when the disparity between the basic standard and expected performance becomes so great that the standard loses its significance. This is in contrast to current standards which require complete revision each year as new budgets are prepared. Since the principal value of basic standards lies in their use as fixed points or bench marks from which to measure changes, they must remain as stable as possible. Under the basic plan less trouble arises even if the standards are not exact, since the comparisons are relative.

Cost Control and Cost Variations

COST CONTROL DEFINED.—Cost control is defined by Jackson (N.A.C.A. Year Book, 1938) as "the guidance and regulation of the internal operations of a business, by means of modern methods of costing, through the measuring of manufacturing and sales performance."

The definition emphasizes the fact that control is a matter of **executive action**; for such control to be effective, the executive acts on infor-

mation obtained by a process of **analysis**. Hence, analysis and control represent a cause and effect relationship.

Cost Control and Cost Analysis.—Cost analysis for managerial control purposes may be defined as the comparison of actual with anticipated or predetermined costs, to determine what variations have occurred, their extent and causes; to discover conditions underlying each cause, and to develop or revise policies, plans, methods, and practices affecting physical facilities, manpower, and organization for the purpose of eliminating unfavorable conditions.

Another type of analysis consists of breaking up accounts and figures into their component elements. This type of analysis is often useful in furnishing detailed statistical information, but unless the latter can be matched against a yardstick of predetermined costs it is not suitable for control purposes.

Cost analysis is also used at times to denote the process of cost accumulation in the absence of a cost system. This, however, is more properly referred to as cost finding.

HOW COST CONTROL IS MAINTAINED.—Raymond P. Marple of the National Association of Cost Accountants has prepared the following outline of **cost control principles:**

1. Accounts should be fitted to organization chart so that costs can be segregated by individual responsibilities.
2. Cost accounts by individual responsibilities should be subdivided under uniform classifications to show nature of expenditures.
3. Goals in the form of standards, budgets, and allowances should be set and constantly kept up to date.
4. Where justifiable cost varies with the rate of activity, variable or flexible budgets and allowances should be developed.
5. Standards, budgets, and allowances should be prepared with the cooperation of the person responsible for each cost item and should be agreed to by him.
6. Variations of actual costs from standard or budget should be segregated and shown in sufficient detail so that responsibility for each variance can be definitely determined.
7. Frequent reports of the costs for which he is responsible should be supplied each person who is responsible for control of any cost element. These reports should emphasize variances of actual costs from standards or budgeted figures.
8. Apportioned or prorated costs over which an executive or subexecutive has no control should not be combined in his cost reports with the costs over which he does have control.
9. As an inducement to those responsible for the control of costs, an incentive system of the "savings-sharing" sort should be developed.

PRINCIPLE OF EXCEPTIONS.—The effectiveness of comparisons of actual and standard costs is based on the principle of exceptions, which makes it possible for the cost accountant to sift from the great mass of his cost data the essential facts needed by management. Having determined a proper standard cost for any given article, the executive may dismiss the question of cost from his mind until such time as there is a discrepancy between the actual and standard cost. When a significantly large cost variation appears, management should be able to analyze it and determine where it occurred, who was responsible, and why it happened. This analysis requires that cost records show in what

Account	100% Std.	Actual Cost	Std. Cost at 62%	Variance	Budget Standard	Explanation	Variations: Oper'n Level	Variations: Management	Variations: Foreman	Foreman's Budget Allow.
Labor:										
Warping		$ 390	$ 355	$— 35	Use std. on oper. rate sheet	10% wage increase		$—35		$ 390
Setting Up		82	98	+ 16	Use std. on oper. rate sheet				$+16	98
Material:										
Cones & Tubes...		35	28	— 7	Use std. on oper. rate sheet				— 7	28
Sizing		270	239	— 31	Use std. on oper. rate sheet				—31	239
Burden:										
Handling	$100	$ 100	$ 62	$— 38	Allow full amt. at all levels		$— 38			100
Repairs	40	20	25	+ 5	Allow full amt. at all levels		— 15		+ 20	40
Supervision	250	250	155	— 95	Drop asst. foreman below 70%	Asst.'s sal. $90	— 5		—90	160
Depreciation	150	150	93	— 57	Allow full amt. at all levels		— 57			150
Insurance	10	10	6	— 4	Allow full amt. at all levels		— 4			10
Taxes	20	20	13	— 7	Allow full amt. at all levels		— 7			20
Boiler & Power..	40	35	25	— 10	Allow actual cost each month		— 10			35
Plant & Bldg.....	20	22	13	— 9	Allow actual cost each month		— 9			22
	$630	$ 607	$ 392	$—215			$—145	$—35	$—92	$1,292
Grand Total ..		$1,384	$1,112	$—272						

Fig. 23. Schedule Showing Responsibility for Manufacturing Expense Variance

department the variation occurred; then from a knowledge of the organization, the person responsible is located, and physical inspection shows the cause of the variation.

TYPES OF VARIANCE CALCULATIONS.—Variances from standard cost can be expressed in either absolute or relative numbers. In the first instance, the variance is computed by subtracting actual cost from standard cost. If the actual exceeds the standard cost, the variance is a negative figure (i.e., unfavorable and represents a variance loss); if actual cost is less than standard cost, the variance is a positive figure (i.e., favorable and represents a variance gain). This method of expressing variances is thus one which centers the attention of management upon dollar amounts of variation from standard costs. It is generally associated with the current or attainable type of cost system.

By the second method, the variance is computed by dividing the standard cost figure into the actual cost figure to obtain the actual cost as a percentage of standard cost. Since standard cost is always the base for comparison, the standard cost is considered 100%. When actual cost has thus been converted to percentages of standard, the actual cost percentage figure can be subtracted from the standard cost percentage figure (100%). The result, which may be either positive or negative depending upon whether actual cost is less or greater than standard cost, is the **cost variance** expressed as a percentage of standard cost. In contrast with the preceding method, a **relative variation** from standard is thus provided. This method is generally used in connection with basic or measurement standards.

These two methods present complementary aspects of the cost figures in such a manner that both are required for a complete understanding of the cost variation that has taken place. Variances which are large in terms of dollars are sometimes so small in terms of **percentages** that they pass unnoticed by management if presented in the latter form alone; on the other hand, a large percentage variation may call attention to a substantial deviation from **standard efficiency**, yet the present actual loss in terms of dollars may be small.

ANALYSIS OF VARIANCES.—Since the total difference between the actual and standard cost is composed of variances arising from a variety of causes, it is necessary to resolve this total into its component parts in such a way that the contribution of each causal factor can be isolated. This is accomplished by taking the factors one at a time, while assuming that the other factors are held constant. Thus it is possible to calculate the influence upon cost of each cause of variation.

COMPUTING MATERIAL AND LABOR VARIANCES.—The method illustrated below represents a mechanical arrangement of the data (Fig. 24) which makes possible the automatic computation of variances by totals and in detail. Under this method an over-all variance is first obtained; this is then broken down in the case of material into usage and price variances. The advantage results from the fact that unskilled clerical labor may be used to make the necessary computations.

The basic assumed facts in Fig. 24 appear in columns 1 to 5, inclusive. Information in columns 1 and 2 is taken from the standard cost card. Column 3 is based on stock ledger cards or other records. Column 4, the standard quantity in the product, is based on production records com-

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
								Variances		
Type of Material	Standard Unit Cost	Actual Unit Cost	Standard Quantity (in product)	Actual Quantity	Standard Quantity at Standard Rate	Actual Quantity at Standard Rate	Actual Quantity at Actual Rate	Over-All (6) − (8)	Usage (6) − (7)	Price (7) − (8)
M-1	$1.00	$ .85	500	520	$ 500.00	$ 520.00	$ 442.00	+$ 58.00	−$20.00	+$ 78.00*
M-2	7.00	7.70	200	205	1,400.00	1,435.00	1,578.50	− 178.50	− 35.00	− 143.50
M-3	2.00	2.20	1,080	1,080	2,160.00	2,160.00	2,376.00	− 216.00	0	− 216.00
Totals.....	....	....	....	....	$4,060.00	$4,115.00	$4,396.50	−$386.50	−$55.00	−$281.50

* − = Unfavorable variances. + = Favorable variances.

Fig. 24. Material Cost Variances

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
								Variances		
Operation	Standard Hourly Rate	Actual Hourly Rate	Standard Hours (in product)	Actual Hours	Standard Hours at Standard Rate	Actual Hours at Standard Rate	Actual Hours at Actual Rate	Over-All (6) − (8)	Time (6) − (7)	Rate (7) − (8)
1	$.50	$.50	500	525	$ 250.00	$ 262.50	$ 262.50	−$ 12.50	−$12.50	$ 0
2	.60	.65	1,500	1,540	900.00	924.00	1,001.00	− 101.00	− 24.00	− 77.00
3	.75	.80	240	230	180 00	172.50	184.00	− 4.00	+ 7.50	− 11.50
4	.95	.90	560	560	$ 532.00	532.00	504.00	+ 28.00	0	+ 28.00
Totals.....	....	....	....	....	$1,862.00	$1,891.00	$1,951.50	−$ 89.50	−$29.00	−$60.50

Fig. 25. Direct Labor Cost Variances

bined with standard and physical requirements as shown by the **standard cost card.** Column 5 of course represents actual production figures, taken from the daily or summary production reports. The remaining columns are merely different combinations of the information in the first four.

The same method is used to obtain **variances for direct labor** (Fig. 25). Efficiency is represented by a time variance, and price by a rate variance. For greater clarity, these are often in turn subdivided. Thus, efficiency is affected by the presence of learners, and a special allowance must therefore be made on this score, so that the foreman is judged only as to conditions under his control. Again, the rate variance is affected by the presence of overtime paid for at premium rates. Such overtime should be set forth as a separate variance in order to show the true extent to which basic wage rates have changed.

ANALYZING OVERHEAD VARIANCES.—There are various methods for analyzing overhead variances. Some of these are shown in Figs. 26 and 27. The following data are needed to provide the necessary information as to variances:

1. Actual overhead is obtained by summing the debits in departmental overhead accounts (departmental **expense distribution sheet**).
2. Actual number of direct labor hours is compiled from clock cards.
3. Budgeted overhead is obtained from the flexible budgets by selecting figures corresponding to the actual number of direct labor hours worked.
4. The number of standard direct labor hours in production is found by multiplying the units produced by the standard labor hour content per unit as shown by the standard cost card.
5. The normal overhead rate is obtained from the standard cost card.

Figs. 26 and 27 are based on the following assumed data:

	Department A	Department B
1. Standard overhead per hour	$ 1.00	$ 3.00
2. Standard allowed hours for actual production	2,000	800
3. Actual hours run	2,065	790
4. Actual overhead expense	$2,011.00	$2,870.00
5. Flexible budget allowances:		
a. For actual hours	$2,032.50	$2,795.25
b. For attained capacity:		
Department A (2,000 hours)	$2,000.00	
Department B (800 hours)		$2,805.00

Capacity and Controllable Variances.—Capacity and controllable variances represent volume and efficiency variances, respectively. According to Reitell and Johnston (Cost Accounting), the following facts form the basis for computing capacity and controllable variances:

1. Cleared-in cost.
2. Budget allowance.
3. Actual expenses.

The **cleared-in cost** is the amount charged to Work in Process, and represents the product of the standard allowed hours for the attained production and the standard hourly rate.

Department	(1) Cleared-In Cost	(2) Allowed Budget	(3) Actual Cost	(4) Variances: Over-All (1) — (3)	(5) Variances: Capacity (1) — (2)	(6) Variances: Controllable (2) — (3)
A	$2,000.00	$2,000.00	$2,011.00	—$ 11.00	$ 0	—$11.00
B	2,400.00	2,805.00	2,870.00	— 470.00	— 405.00	— 65.00
Totals.....	$4,400.00	$4,805.00	$4,881.00	—$481.00	—$405.00	—$76.00

Fig. 26. Overhead Variances

Department	(1) Standard Hours at Standard Rate	(2) Actual Hours at Standard Rate	(3) Budget for Actual Hours Worked	(4) Actual Expense	(5) Variances: Over-All (1) — (4)	(6) Variances: Efficiency (1) — (2)	(7) Variances: Activity (2) — (3)	(8) Variances: Expense (3) — (4)
A	$2,000.00	$2,065.00	$2,032.50	$2,011.00	—$ 11.00	—$65.00	+$ 32.50	+$21.50
B	2,400.00	2,370.00	2,795.25	2,870 00	— 470.00	+ 30.00	— 425 25	— 74.75
Totals.....	$4,400.00	$4,435.00	$4,827.75	$4,881.00	—$481.00	—$35.00	—$392.75	—$53.25

Fig. 27. Overhead Variances

The **budget allowance** is the expense allowed at the attained level of production. It is usually obtained from the flexible budget, by interpolation, if necessary.

Efficiency, Expense, and Utilization Variances.—The **expense variance** is the result of spending more or less than the budgeted allowances for indirect materials, indirect labor, etc., at the attained activity level.

The **efficiency variance,** also called **controllable** variance, is the result of using more or less than the standard amount of overhead service. It arises whenever the actual direct labor hours or machine-hours differ from the standard allowed hours.

The **utilization variance,** frequently referred to as **capacity** variance, or **volume** variance, is the result of operating more or less than the normal number of hours in any given budget period.

The computation of variances under this method is shown in Fig. 27. Note that the resulting variances differ from those in Fig. 26, first in the kind of information obtained and secondly in the method of computation.

Cost Reports

ADAPTING REPORTS TO EXECUTIVE NEEDS.—The cost department must provide different types of reports fitted to the needs of executives in various positions requiring different information. It must know who the user of the report is to be, and what needs he has in order to render the most helpful type of service in the complete and accurate presentation of information required.

In developing the usefulness of cost and operating reports, three classes of executives and their needs must be recognized:

1. Minor executives, including foremen, section chiefs, gang bosses, master mechanics, chief storeskeeper, chief clerk, etc. These are sometimes referred to as junior executives and usually represent department heads.
2. Intermediate executives, including factory superintendent, auditor, works accountant, purchasing agent, etc. Under this heading are included those executives whose scope of activity extends over more than one department; e.g., executives located in the factory office or offices; also executives who, while nominally department heads, are concerned with problems of coordination affecting the entire business in all its branches.
3. General executives, including corporate officers, and those commonly associated with the general sales and administrative functions. These include the general manager, sales manager, controller, etc.

These groups differ in the ways in which their influence is exerted and in their needs for information. There is no precise line of demarcation from one class to the next.

COST REPORTS AND STANDARDS.—By comparing actual with standard costs, variances are obtained which must be analyzed in reports as to causes. The success of a standard cost system is largely dependent on the **interpretation of operating results** as reported on periodic statements. These should be designed to reveal **variations in cost** and as far as possible to state the reasons for them.

The modern trend in cost reports is in the direction of greater use of quantity engineering data as opposed to dollar cost figures. This is

because standard costs are based on physical standards, and hence reports are prepared more quickly by letting the **physical standards** speak for themselves rather than translating them into **standard costs.** The tendency has gone so far that many variable expense budgets are prepared in terms of men and man hours rather than in terms of dollars. In this way closer cooperation between the cost and the operating departments is obtained and a greater recognition results on the part of the cost department of the problems faced by the operating department.

REQUISITES OF COST REPORTS.—In general, the rules to be observed in the preparation and presentation of reports fall into four groups:

1. **Compactness,** economizing the executive's time and effort. This means that the executive should be presented first with a summary which, by itself, gives him a bird's-eye view of conditions. The **principle of exceptions** may be utilized in the construction of this summary, thus eliminating items which are in line with standards, for these do not require further study or action.

2. **Physical make-up,** i.e., the form of the report. This involves use of descriptive titles, proper dating, clearness and conciseness of the various forms employed, graphic presentation of results, and good arrangement of data.

3. **Timeliness.** Executives who have cooperated in setting standards for which they are to be held accountable must have prompt and accurate reports of their actual performance. Some companies provide foremen with comparisons of performance by the following day. According to Haskins and Gilmore (N.A.C.A. Bul., vol. 21), a certain textile plant presents detailed reports weekly of controllable expenses to foremen, superintendents, controller, and president. Other companies get successful results with monthly reports for operating men because the foremen are so familiar with standards as to be able to exercise effective daily control with a minimum of current information.

4. **Content.** In general, those items which are controllable by a given executive need be emphasized in the report he receives. There is no objection to placing in a report information about noncontrollable costs; in fact, to do so may aid executives to acquire a broader understanding of the company's problems. But there must be a strict separation between controllable and noncontrollable items in order that expense control may be positive.

MATERIAL COST REPORTS.—It is desirable to separate material cost variances resulting from purchasing activities and cost variances resulting from manufacturing activities. The former account largely for price variations, the latter for usage variations. Each of these variations may be subdivided as to causes. The following list of causes is suggestive only:

1. **Price variance** sources:
   - a. Changes in market price.
   - b. Improper purchasing policies.
     - (1) Changes in purchasing policies.
     - (2) Wrong quantity.
     - (3) Wrong quality or grade.
   - c. Errors in recording.

2. **Usage variance sources:**
   a. Changes in design of product, machinery, or tools.
   b. Changes in methods of processing or fabricating.
   c. Spoilage and waste (especially excess spoilage) in production.
   d. Losses in storage of raw materials, finished products, and finished goods through spoilage, theft, waste, etc.
   e. Damage during handling.
   f. Too rigid inspection.
   g. Errors in accounting charges.

Price Variance Reports.—Fig. 28 is a report of material price variations suggested by Perry (N.A.C.A. Year Book, 1941). Its purpose is to separate the price variance factor from the usage factor on both raw and manufactured materials. The usage factor is subjected to later analysis on the basis of controllable efficiencies. This report compares actual against standard in dollars at the time of purchase, including standard and actual unit prices and quantity purchased. Both the mill vice-president and purchasing agent receive the report.

Material Usage Reports.—A usage report described by Lause (N.A. C.A. Year Book, 1935; also N.A.C.A. Bul., vol. 19) expresses usage standards in pounds for each product specification. A daily report issued by the cost department to foremen shows only those items on which the actual weights used exceed standard weights allowed. Foremen thus concentrate daily on those items in excess of standard. A weekly report, comparing actual and standard usage, is prepared by the cost department by product lines. It lists the complete performance in relation to allowable standards. For each model of automobile running board the total number produced during the week is shown, total weight of material used, unit actual weight, standard weight, the physical and dollar variances on each product for the week and cumulative to date. A monthly report summarizes the cost variances by products.

A similar situation exists with respect to scrap and spoilage (Fig. 29). Note that an allowance for these items is included in the standard. The report, therefore, is intended to focus attention on **excess** scrap and spoilage.

LABOR COST REPORTS.—The analysis of direct labor cost variances follows the same general plan as that for direct material cost variances, but the causes of the variances differ. A list of possible labor variance causes follows:

1. **Rate variance sources:**
   a. Wage rate changes.
   b. Change of payment plan, e.g., from piecework to time work, etc.
   c. Change in grade of labor used.
   d. Clerical errors.
2. **Time or efficiency variances** as affected by:
   a. Selection of workers.
   b. Training of workers.
   c. Frequency of change-overs.
   d. Labor turnover.
   e. Incentive wage payment plan.
   f. Working conditions.
   g. Working hours.

	Standard Price	Actual Price	Quantity Purchased	Total Value at Standard	Total Value at Actual	Price Variations
Raw Materials:						
Warp Yarn—						
10/2 Carded	.28	248	54,136	$15,158	$13,447	$1,711
20/2 "	.31	.30	10,051	3,116	3,015	101
Etc.						
Spool Yarn						
20/2 Carded						
30/2 "						
Etc.						
Bobbin Yarn						
80/2 Combed						
90/2 "						

Fig. 28. Material Price Variance Report

Scrap Cost by Responsibility—Week Ending April 3, 19—

Responsibility: Foreman	Responsibility: Division	Direct Labor	Scrap Cost	Unit Scrap Cost Per Dir. Labor Dollar	Standard Unit Scrap Cost Per Dir. Labor Dollar	Variance From Std. Week End. 4/3	Variance From Cum. 8/1-4/3
	Manufacturing Division						
T. Jones	Rubber Mill—Antenna—1141-X	$	$	$	$	$	$
	Rubber Mill—Duprene						
	Rubber Mill—Brake Hose						
	Misc. Manufacturing						
	Total Manufacturing Division	$ 54,833.63	$ 3,777.80	$.06889	$.06700	$—103.95	$— 8,703.25
	Material Division	$	$	$	$	$	$
	Engineering Division						
	Sales Division						
	Inspection Division						
	Plant Not Determined						
Total Week Ending April 3, 19—		$ 54,833.63	$ 4,524.76	$.08252	$.08360	$ 59.53	....
Total Cum. Car Model Year 8/1-4/3		$1,500,226.05	$142,988.44	$.09531	$.08360	....	$—17,569.55

Factory Accounting Dept.

Fig. 29. Weekly Scrap Report

h. Honesty among workers.
i. Selection of machines and tools.
j. Changes in design of product.
k. Changes in machinery, tools, or methods of production.
l. Adequate accounting or production records.

The immediate **control of direct labor cost** is, in most concerns, in the hands of foremen. This requires that they be provided with reports daily or weekly to help them in keeping this element of cost within standard limits. Where the rates paid are determined by a contract with a union or by executives other than foremen, only the usage and selection of the correct grade of labor is chargeable to foremen.

Rate Variances.—The most obvious cause of rate variances is occasioned by authorized changes in the wage structure. Such changes should come only as a worker is moved from one job class to another, on the basis of a carefully worked out policy as to job classification and salary ranges.

Actually there are two principal causes of a wage rate variance, aside from authorized wage increases:

1. Employment of high-rate employees on low-rate tasks.
2. Overtime work.

In the former case an increase in the average hourly rate of a department takes place, although no one has been given a wage increase. In the case of overtime a similar increase takes place, due to the premium wage paid for the excess hours. The presence of both should be checked constantly through reports.

Time Variances.—The reasons for excess labor time are more numerous than those which create labor rate variances, but they are also harder to discover and control. Consequently, the bulk of labor reports is devoted to the time element.

A comparison between estimated or budgeted unit man-hours and actual unit man-hours, revealing either a gain or loss, is provided for in Fig. 30. Study of such a report may lead to an investigation of the effectiveness of labor and to a revision of labor policies. Tracing back to causes, there may be revealed that the right man was not placed in the right job; that a foreman has failed to secure cooperation of workers; that training and instruction of new workers was inefficient and faulty; that wage incentive plans were lacking; or that labor turnover was

DIRECT LABOR
WEEKLY GAIN AND LOSS REPORT

FOREMAN: *L.E. Pratt* DEPARTMENT *#18* WEEK ENDING: *February 11, 19 –*

TYPE OR STYLE	BUDGET			ACTUAL			GAIN PER UNIT	LOSS PER UNIT	REMARKS
	Production	Unit Man-Hours	Total Man-Hours	Production	Unit Man-Hours	Total Man-Hours			

FIG. 30. Direct Labor, Weekly Gain and Loss Report

excessive. Information thus presented and compared has a direct bearing upon individual productivity of workers under the foreman of a department. The report covers a week, but a similar report should be prepared daily. The latter represents standard practice in the case of one automobile manufacturer, where a daily plant report includes a comparison of actual and standard labor costs.

MANUFACTURING EXPENSE REPORTS.—Determination of the proper allowance for a given expense is the first step in its control. Once proper allowances are set, control is obtained largely through determination of an efficiency variance by comparison of actual expenditures with amounts allowed for a given rate of activity. However, since the expense absorbed differs from that allowed at all but the normal rate of activity, there is also a volume variance.

The expense variances may be classified as follows:

1. **Spending variance** sources:
   a. Using wrong grade of materials.
   b. Using wrong grade of labor.
   c. Failure to get most favorable terms in buying.
   d. Changes in market price.
2. **Efficiency variance** sources:
   a. Waste of materials.
   b. Inefficient labor performance.
   c. Failure to curtail usage of materials and services to correspond with output level.
3. **Utilization variance** sources:
   a. Controllable causes—
      Employees waiting for work.
      Avoidable machine breakdowns.
      Lack of operators.
      Lack of tools.
      Lack of instructions.
   b. Noncontrollable causes—
      Decrease in customer demand.
      Calendar fluctuations.
      Excess plant capacity.

The first group is best studied through budget comparisons, the second and third through departmental cost reports.

Budget Comparisons.—When deviation from normal output volume takes place, a flexible budget automatically sets before the various executives the corrected standard for the output level actually achieved. With such standards always in view, it becomes a relatively easy matter to keep the rate of spending of each item of overhead adjusted to the rate of output; i.e., each item is kept within limits predetermined to be proper.

A weekly budget report for a weave room in a textile plant is described by Haskins and Gilmore (N.A.C.A. Bul., vol. 21) and shown in Fig. 31. Standard figures for direct labor and indirect labor are derived from actual production of cloth, multiplied by unit standard costs. Direct comparison of actual and standard gives gain or loss by functions for the week. This report is presented to the foreman two days following the end of the work week and has a marked effect upon his ability to attain timely and efficient control of operations.

WEAVE NO. 1 & 2

Standard Looms 1950 — Week Ending Feb. 3, 19—

Actual First Shift	1464	Standard Yards	500,000
" Second "	1469	Actual "	674,141
" Third "	1385		
	4318		

OCCUPATION	CODE	STANDARD	ACTUAL	GAIN	LOSS
Supervision and Clerical......	001	$ 654.91	$ 706.54		$51.63
DIRECT:					
Weavers	135	7,626.74	7,610.88	$ 15.86	
Twisters In	123	485.70	485.70	....	
Spool Boys	124	8.04	19.49		11.45
Total Direct		8,120.48	8,116.07	15.86	11.45
INDIRECT:					
Fixers	etc.	etc.	etc.	etc.	etc.
Oilers					
Cleaners					
Sweepers					
Waste Man					
Cut Stampers					
Total Indirect		7,422.48	7,299.94	189.01	66.47
Total Direct and Indirect.		15,542.96	15,416.01	204.87	77.92
Net Gain		126.95		126.95	
Learners			21.95		
Allowances			.82		
Samples			365.56		
Changing		1,508.13	884.94	623.19	
Extra Work			.86		
Inventory			26.73		
TOTAL PAYROLL			17,423.41		

Std. Loom Hours	156,000	% of Actual to Standard	99.2%
Act. " "	179,464	% of Actual Indirect to Direct	89.9%
		% of Relative Activity	93.5%

FIG. 31. Weekly Budget Report

Departmental Cost Reports.—Fig. 32 illustrates the analysis of expenses by cost centers. Separate reports show the detailed budget for each cost center.

Volume Variance.—The difference between budgeted expense and applied expense is a volume variance, and represents idle capacity. The idle time report presented in Fig. 33 provides columns for the principal cause for idle time. It gives the number of hours each individual item of equipment is idle; number of hours it should have run based on standard hours of the shop; number of overtime hours run; and per cent of total idle time to standard hours and also to total hours actually run. This report is a valuable record for the foreman, as it reflects each week the running condition of his equipment, showing both success and failure of effort to eliminate idle time. As machine rates are figured on

	Standard Cost	Actual Cost	Cost Variations	Cause of Variations			Foremen's Budget	
				Level of Operations	Management Changes	Foremen's Efficiency	Budget Allowance	% Actual of Budget
Productive Cost Centers:								
Yarn Preparation								
Bobbin								
Warp								
Weaving								
Mending								
Bleach								
Dress								
Cutting and Splitting								
Finishing								
Wrap and Label								
Stock Room								
Total	$144,864	$138.799	$6.065	$5.150	$1.110*	$2.025	$140.824	98.6

* Denotes red figures.

[Detailed figures purposely omitted.]

Fig. 32. Analysis of Expense Variations by Cost Centers

IDLE MACHINE REPORT

_______________ Dept. Period Ending _______________ 19____

	Machine Numbers	Stand Hours	Running Hours			Idle Hours									Percentages		
			Regular Stand Hrs	Overtime Hours	Total Hrs Run	No Operator	No Material	No Orders	Repair	No Power	Await Set Up	Await Tools	Await Inst.	Total Idle Hrs.	% Stand	% Run	

Fig. 33. Idle Machine Time Report

COMPARISON OF COSTS WITH ESTIMATES

Cost Element	No. 1 Quota	No. 1 Actual	No. 1 Under	No. 1 Over	No. 2 Quota	No. 2 Actual	No. 2 Under	No. 2 Over	No. 3 Quota	No. 3 Actual	No. 3 Under	No. 3 Over
Total cost	30,000	37,650		7,650	38,000	35,490	2,510					
Materials	11,100	14,600		3,500	14,060	14,000	60					
Labor	12,000	16,200		4,200	15,200	14,400	800					
Applied overheads												
Total	6,000	5,700	300		7,600	6,200	1,400					
Machine shop 1	1,800	2,000		200	2,280	2,100	180					
Machine shop 2	2,100	1,800	300		2,660	1,900	760					
Heat treating	1,500	1,200	300		1900	1,400	500					
Assembly	600	700		100	760	800		40				
Other expenses.												
Total	900	1,150		250	1,140	890	250					
Tools	450	600		150	570	500	70					
Set-ups	300	500		200	380	300	80					
Miscellaneous	150	50	100		190	90	100					

Original Estimate

Per Unit	
Direct materials	$3 70
Direct labor	4 00
Overheads:	
Machine shop 1	60
Machine shop 2	70
Heat treating	50
Assembly	20
Tools	15
Set ups	.10
Miscellaneous	05
	$10.00

Contract Terms:

Amounts

10,000 to 11000 units to be delivered in lots of not less than 2,500

Total estimated tool cost $1,500

Total estimated set-up cost 1,000

Original Scheduling:

	Units
First production order	4,000
Second production order	4,000
Third production order	3 000
	11,000

Results to date:

First production order	3,000
Second production order	3,800
Now scheduled	4,000
	10,800

FIG. 34. Progress Chart, Graphical Analysis of Actual with Estimated Costs

normal capacities, there is no idle machine loss in money unless the machine runs less than normal time.

SUMMARY COST REPORTS.—It is the duty of the cost accountant to provide the general executives with summarized reports which serve to keep them informed concerning the general conditions within their company and to help them control activities of their immediate subordinates. In general, the reports represent the results of the work of the general or financial accountant and the cost accountant. The general accounting department is primarily interested in the compilation of the balance sheet and the profit and loss statement, the forecast of the cash position and such other matters as are of importance in revealing the status of the business as affected by external conditions. The cost accountant supplies the details of operations particularly those for the **cost of production** which reflect the forces at work internally.

Simplicity and condensation are the keynotes for executives' reports. The latter include the following:

1. Balance Sheet.
2. Earnings Statement.
3. Plant Summary.

Below the level of the reports just mentioned are the supporting data in the hands of intermediate and minor executives. These reports may, however, be called for by the major executives, particularly if they want explanations and analyses of the condensed figures in the summary reports. In general, the detail reports cover for the manufacturing division the details of what happens in the **cost centers**, that is, the departmental reports. These are the reports furnished to the works manager, plant superintendent, and foremen.

GRAPHIC EXECUTIVE CONTROL CHART.—Boyan (Handbook of War Production) shows a **Gantt-type** operating control chart (Fig. 34). The purpose of this chart is to make comparison of results with a predetermined plan or standard. Charts of this type can be made to show anything of interest to the executive in question, such as what work is ahead in plant, orders received month by month, data concerned with the operation of business, including costs and expenses, idleness, inventories, and finally, pertinent facts regarding the working force such as accidents, labor turnover, earnings, and individual production. For each of these items schedules of standards are developed and actual performance is plotted against these predetermined figures.

SECTION 24

FACTORY BUDGETS

CONTENTS

with forecasting the cash position of a concern at the end of a budget period if the contemplated budget were adopted. This may be further broadened into a general forecasted balance sheet, in which the effect of the budget is reflected for all balance sheet accounts. Finally, a forecasted profit and loss statement is included showing the probable results of the budgeted costs and the extent to which adequate profit margins are maintained.

The presentation in this Section deals largely with the factory budget.

PURPOSE OF BUDGET.—Although a budget is primarily a plan of action to accomplish predetermined objectives, the concept of control rather than planning developed as a result of the use of the budget after its origination. Operations can be controlled and coordinated properly only after a master plan has been devised to serve as a guide and standard of comparison. The budget planning concept increases the importance of the budget because it gives management the basis of business action and direction toward desired results as well as a basis for comparison and a mechanism for control. Control is obtained by comparing actual results with planned operations as contained in the budget and taking corrective action in case a discrepancy occurs.

Proper budget planning and effective budgetary control affect all elements and activities of industrial operation. The budget is a comprehensive over-all plan of operation for a considerable period of time. The plan involves the utilization of all factors of production—plant, equipment, materials, and labor—control of all the elements of cost, and realization of the objectives of income and profit. The budget is designed to show both the estimated sales and profit and the costs of clearly defined manufacturing operations and methods.

Sinclair (Budgeting) states that the aims or purposes of the budget can be presented with considerable definiteness as follows:

1. Establish a definite objective of performance for the enterprise.
2. Formulate executive policies as to future operations.
3. Promote cooperation in acceptance of policies and execution of plans.
4. Determine limits to which expenditures are to be confined.
5. Determine what funds will be required, when they will be needed, and from what sources they will be derived.
6. Set up comparisons and checks to show currently the degree and quality of operating performance.
7. Indicate when and where changes must be made in current operation in order that the planned objective may be realized.

As adapted from Davis (Industrial Organization and Management), some of the advantages to be expected from budgeting are:

1. The necessity for forecasting sales and the required amounts of the various production factors impresses on executives the importance of more refined methods of determining future plans.
2. Administrative executives can make fairer decisions because they have a standard of performance by which to interpret the reports they receive on actual results.
3. Operating executives can use their own initiative within the predetermined standards of performance in executing their responsibilities.
4. The eventual computation of *variations* from budgeted figures gives a basis for determining their causes and for eliminating them in future plans.

5. The necessity for establishing budgets on the basis of organization divisions results in a valuable study of the organization itself. Unsatisfactory groupings of functions may be corrected and organization unbalance eliminated.

LIMITATIONS OF THE BUDGET.—Budgets have their limitations which may be summarized as follows:

1. The preparation of the budget plan is based on forecasts of future conditions, on estimated data based upon the judgment of executives in interpreting available data. Thus, success of a budget plan depends upon the validity of the data at hand and the intelligence and judgment of management in forecasting events.

2. Individual concerns may be largely influenced in their operations by style, season, special order, or a similar factor that makes forecasting and budget planning difficult. Inasmuch as a budget period usually runs for several months or a year, business concerns whose operations are dependent upon factors of uncertainty must be guided by the **principle of flexibility** in establishing a budget.

3. After a budget plan has been approved and adopted, it must be properly administered and executed to be successful. The budget plan cannot be expected to function automatically or as a substitute for administrative and operative management.

4. A reasonable amount of time is necessary to prepare and operate a successful budget plan. Anticipated results may not be obtained immediately. It often requires weeks or months for a company to install a budget system, instruct its personnel to cooperate in its use, and make it function properly.

REQUISITES FOR BUDGETING.—Sinclair (Budgeting) states the requirements which must be satisfied for the successful operation of a budget plan:

1. An accountable business organization in which authority and responsibility are properly defined and developed.
2. Clearly defined business policies.
3. An adequate supply of accurate information and pertinent data for the purpose of preparing the budget estimates.
4. A definite plan for the administration of the budget after it is set up.
5. A well-devised and complete general accounting system organized to furnish basic information, and to prepare period-to-period comparisons of estimate and performance.
6. An adequate cost system controlled by the general books of account.
7. An accounting classification of the general ledger and of the cost and other subsidiary ledgers to be used in classifying the budget estimates.
8. Perpetual inventory records of stores, raw materials, work in process, finished goods, and plant and equipment.
9. A schedule of the regular weekly or monthly reports and departmental expenses and monthly financial statements.

RELATION OF BUDGETING AND ACCOUNTING.—Although a proper system of accounting is necessary for any business, it is especially essential for a concern operating under a budget program. MacDonald (Practical Budget Procedure) states that two main points emphasize the close relation between budgeting and accounting:

1. **Comparison of estimates and expense.** . . . since one of the fundamental prerequisites to good budgetary control is the ability to check actual

performance with previous estimates, both sets of figures must be comparable. This means that the detailed accounts, which in turn comprise the chart of accounts, must be classified in terms of organization authority and responsibility, and that budgets must be compiled according to the accounting classification.

2. **Standard cost accounting.** Standard costing is an ally of budgeting, ably supports it, and should really be considered a part of it, but standard costs alone do not constitute a budget.

BUDGET ORGANIZATION.—If a company has a strong chief executive who can perform the coordinating function, the budget organization is simplified. He becomes the chairman, or the chairman ex officio, of the budget committee. With him are associated the treasurer, sales manager, works manager, purchasing agent, and the controller or chief accountant. This is a typical budget organization used by many companies. Frequently, however, the responsibility for the budget program is placed in the hands of the treasurer, or controller, or assistant to the president. If such is the case, care must be taken to obtain the full cooperation of the president.

Budget organizations vary with different companies. Regardless of the individual situation, the responsibility and authority for the budget plan must be properly placed and delegated. There must be a budget chairman and he must have the cooperation of department heads and corporate officers. This fundamental managerial law pertaining to authority and responsibility is expressed by Alford (Laws of Management Applied to Manufacturing) as follows:

> Responsibility for the execution of work must be accompanied by the authority to control and direct the means of doing the work.

Duties of the Budget Chairman.—Regardless of which officer in a business concern serves as budget chairman, he will have certain prescribed duties t o perform. MacDonald (Practical Budget Procedure) lists them as follows:

1. To receive from departmental heads periodic estimates.
2. To transmit these estimates with such recommendations as he may deem necessary. He may combine and summarize these estimates so that they may be submitted in the most useful form.
3. To supply those who finally approve the budget with all the available information which will assist them in considering the estimates.
4. To receive the estimates as approved and transmit them to the departmental heads.
5. To receive periodic reports prepared by the operating departments or the accounting department, showing the performance for each department during the budget period.
6. To transmit periodic reports to the management showing a comparison between actual and estimated performance for each department, and to make recommendations with reference to revisions which he deems necessary.
7. To transmit to the departmental heads any revisions of the original estimates which may be made.
8. To recommend any changes in the budget procedure which he may believe necessary.

BUDGET MANUAL.—In an organization of considerable size, procedures and policies affecting a number of persons should be reduced to writing. A budget program, since it covers activities of all branches and departments, is best understood if carefully prepared and transmitted in

written form to all responsible parties. McKinsey (Budgetary Control) presents a complete manual on budgeting procedure as worked out for a company having sales of about $6,000,000 a year. This manual covers the **budget program** as follows:

1. Statement of the function of each executive with reference to budgeting.
2. Steps in the preparation of the sales budget, when submitted, reviewed, and approved by budget committee and general manager, and nature of reports and revision of the sales budget.
3. Handling of the production budget.
4. Steps in building up the labor, materials, and expense budgets and outline of the reports used to follow up these budgets.
5. Development of the plant and equipment budget.
6. Procedure for control of departmental expense and development of departmental expense budgets.
7. Development of the financial budget.
8. Preparation of preliminary estimated financial statements.

In case of each of these items, very complete and definite statements are made so that the manual is in reality a useful guide in preparing the budget. This manual has been diagrammed and is reproduced here as Fig. 1.

It should not be expected that the diagram can be used by every business. It is reproduced to show the coordinated and interrelated work necessary, and the need for a definite program covering every aspect of budgeting procedure.

BUDGET PERIOD.—Establishment of a budget presupposes a period to be covered by the budget. All factors of the business are not subject to same influences and different periods may be used in handling different phases of the budget. Most manufacturing companies budget for a year and provide for a revision of the budget at the start of each quarter. One company doing an annual volume of over $20,000,000 follows this plan, keeping the original forecast alive as a general goal but changing forecasts as between products and periods.

Another practice quite widely used is to keep a constant **forecast one year in advance** by adding a month as each month is completed. For example, a company with such a forecast, upon the completion of operations for February, 1944, would add a forecast for February, 1945, thus completing a year's forecast to March 1, 1945.

A number of factors determine the length of the budget period. Among them are:

1. Normal merchandise turnover period.
2. Period required to produce the product.
3. Method of financing.
4. Stability or uncertainty of market conditions.
5. Adequacy of historical data usable for budgeting.
6. Length of fiscal period.
7. Seasonal or style influences.
8. Completeness of line manufactured.

Variations due to the calendar at times mar the true situation and present a record which is seen to be too favorable on careful analysis. In budgeting it may lead away from significant check-up points that provide natural breaks between periods. Every business which establishes a budget period must forget the calendar for the moment and seek its

	SALES BUDGET	PRODUCTION BUDGET
A. SALES MANAGER	1. Anticipated sales for budget period, by grade and put-up, to E on or before 1st day of the 3rd week preceding budget period 2 Receive approved Sales Budget from E 3. Receive revised Sales Budget from E on or before 15th day after close of period.	
B. WORKS MANAGER	1. Receive copy of sales estimate from E on or before 3rd day of 3rd week preceding budget period.	1. Transmit estimate of production to E on or before 3rd day of 2nd week preceding budget period. 2. Receive approved Production Budget from E. 3 Report of production to E on or before 5th working day after close of period. 4 Receive revised Production Budget from E.
C. GENERAL MANAGER		
D. BUDGET COMMITTEE	1. Revise and approve within 2 days after receipt from E—return to E. 2. Receive comparison of estimated and actual sales from E—report any revisions in Sales Budget to E on or before 15th day after close of period.	1. Revise and approve within 2 days after receipt from E—return to E 2 Receive comparison of estimated and actual production from E—report any revisions in Production Budget to E on or before 12th day after close of period.
E. ASSISTANT TO THE GENERAL MANAGER	1. Submit copy of anticipated sales to B within 2 days after receipt from A 2. Original estimate to D on or before the 1st day of 1st week preceding budget period 3 Receive approved Sales Budget from D and transmit to A 4. Comparison of estimated and actual sales together with recommendations to D on or before 10th day after close of period. 5. Transmit revision in Sales Budget to A on or before 15th day after close of period.	1 Receive and transmit estimate of production to D on or before 1st day of 1st week preceding budget period 2 Receive approved Production Budget from D and transmit to B. 3 Comparison of estimated and actual production to D on or before 10th day after close of period 4. Transmit revisions in Production Budget to B on or before 15th day after close of period.
F. STATISTICAL DEPT.	1. Report of actual sales for the period to E on or before the 5th working day after close of period	
G. ACCOUNTING DEPT.		
H. PURCHASING AGENT		

FIG. 1a. Chart of

PAY-ROLL BUDGET	STORES PURCHASE BUDGET	MATERIAL BUDGET
1. Estimate of the Sales dept. pay-roll to E on or before 10th day preceding budget period. 2 Receive approved Pay-roll Budget from E. 3. Receive revised Pay-roll Budget from E on or before 15th day after close of period.		
1. Estimate of the factory pay-roll to E on or before 10th day preceding budget period. 2 Receive approved Pay-roll Budget from E. 3. Receive revised Pay-roll Budget from E on or before 15th day after close of period.	1 Estimate of stores purchases to E on or before 13th day preceding budget period 2 Receive approved Stores Purchase Budget from E 3. Receive revised Stores Purchase Buget from E on or before 15th day after close of period.	1. Estimate of material required to E on or before 10th day preceding budget period.
1. Estimated administrative pay-roll to E on or before 10th day preceding budget period. 2. Receive approved Pay-roll Budget from E. 3. Receive revised Pay-roll Budget from E on or before 15th day after close of period.		
1. Revise and approve within 2 days after receipt from E—return to E. 2. Receive comparison of estimated and actual pay-roll from E—report any revisions in Pay-roll Budget to E on or before 12th day after close of period.	1. Revise and approve within 2 days after receipt from E—return to E. 2 Receive comparison of estimated and actual stores purchases from E—report any revisions in Stores Purchase Budget to E on or before 12th day after close of period.	1 Revise and approve within 2 days after receipt from E—return to E. 2. Receive comparison of estimated and actual material purchases from E—report any revisions in Material Budget to E on or before 12th day after close of period.
1. Receive and transmit estimated pay-roll to D on or before 1st day of 1st week preceding budget period. 2. Receive approved Pay-roll Budget from D and transmit to A, B, and C. 3 Comparison of estimated and actual pay-roll to D on or before 10th day after close of period 4. Transmit revisions in Pay-roll Budget to A, B, and C on or before 15th day after close of period.	1 Receive and transmit estimated stores purchases to D on or before 1st day of 1st week preceding budget period 2 Receive approved Stores Purchase Budget from D and transmit to B 3. Comparison of estimated and actual stores purchases to D on or before 10th day after close of period 4. Transmit revision of Stores Purchase Budget to B on or before 15th day after close of period.	1. Receive and transmit estimated material requirements to H on or before 10th day preceding budget period. 2 Receive and transmit estimated material purchases to D on or before 1st day of 1st week preceding budget period. 3. Receive approved Materials Budget from D and transmit to H. 4 Comparison of estimated and actual material purchases to D on or before 10th day after close of period. 5 Transmit revision of Material Budget to H on or before 15th day after close of period.
1. Report of actual pay-roll to E on or before 8th day after close of period.	1. Report of actual stores purchases to E on or before 8th day after close of period.	1. Report of actual material purchases to E on or before 8th day after close of period.
		1. Receive estimated material requirements from E—submit estimate of material purchases to E on or before last day of the 2nd week preceding budget period. 2 Receive approved Material Budget from E. 3 Receive revised Material Budget from E on or before 15th day after close of period.

Budget Procedure

PLANT AND EQUIPMENT BUDGET	MISCELLANEOUS EXPENSE BUDGET	FINANCIAL BUDGET
1. Estimate of expenditures for equipment to C on or before 15th day preceding budget period. 2. Receive approved Plant and Equipment Budget from E. 3. Receive revised Plant and Equipment Budget from E on or before 15th day after close of period.	1. Estimate of miscellaneous expenses by departments to E on or before 10th day preceding budget period. 2. Receive approved Miscellaneous Expense Budget from E. 3. Receive revised Miscellaneous Expense Budget from E on or before 15th day after close of period.	
1. See SALES MANAGER. 2. See SALES MANAGER. 3. See SALES MANAGER.	1. See SALES MANAGER. 2. See SALES MANAGER. 3. See SALES MANAGER.	
1. Receive and approve estimates of expenditures for plant and equipment—return to E on or before 10th day preceding budget period. 2. Receive approved Plant and Equipment Budget from E. 3. Receive revised Plant and Equipment Budget from E on or before 15th day after close of period.	1. See SALES MANAGER. 2. See SALES MANAGER. 3. See SALES MANAGER.	1. Revise and approve estimate of cash receipts and disbursements from E. 2. Receive Financial Budget.
1. Revise and approve within 2 days after receipt from E—return to E. 2. Receive comparison of estimated and actual expenditures for plant and equipment from E—report any revision in Plant and Equipment Budget to E on or before 12th day after close of period.	1. Revise and approve within 2 days after receipt from E—return to E. 2. Receive comparison of estimated and actual miscellaneous expense from E—report any revisions in Miscellaneous Expense Budget to E on or before 12th day after close of period.	1. Revise and return within 2 days after receipt from E. 2. Receive comparison of estimated and actual cash receipts and disbursements—report any revisions in Financial Budget to E.
1. Receive approved estimates of expenditures for plant and equipment from C—transmit to D on or before 1st day of 1st week preceding budget period. 2. Receive approved Plant and Equipment Budget from D and transmit to A, B, and C. 3. Comparison of estimated and actual expenditures for plant and equipment to D on or before 10th day after close of period. 4. Transmit revision of Plant and Equipment Budget to A, B, and C on or before 15th day after close of period.	1. Receive and transmit estimated miscellaneous expense to D on or before 1st day of 1st week preceding budget period. 2. Receive approved Miscellaneous Expense Budget from D and transmit to A, B and C 3. Comparison of estimated and actual miscellaneous expense to D on or before 10th day after close of period. 4. Transmit revision of Miscellaneous Expense Budget to A, B, and C, on or before 15th day after close of period.	1. Prepare estimate of cash receipts and disbursements— submit to C. 2. Submit estimate of cash receipts and disbursements, approved by C, to D on or before 1st day of 1st week preceding budget period. 3. Receive approved Financial Budget from D and transmit to C. 4. Comparison of estimated and actual receipts and disbursements to D on or before 10th day after close of period.
1. Report actual expenditures for plant and equipment to E on or before 8th day after close of period.	1. Report actual miscellaneous expense to E on or before 8th day after close of period.	

FIG. 1b. Chart of Budget Procedure (*Cont'd*)

normal economic cycle. All the above factors must be kept in mind in establishing that period. In general, it is true that most budgets attempt a forecast for a year in advance but are subject to revision monthly or quarterly as new developments become evident. If business is on a calendar year basis, budget data are assembled during November and December of the year previous to that budgeted.

PREPARATION OF A BUDGET.—The usual practice is to begin with an estimate of sales volume. Another method is to start with an estimate of profit or expense. The following methods are in current use:

1. A study of the sales possibilities and probabilities may be made for an individual company's sales estimate by:
   a. Study of past sales performance.
   b. Thorough market analysis and forecasting.
2. Analysis of the sales volume by products and departments.
3. Preparation of a budget by estimating the profit needed to meet obligations and give an adequate return on capital to its owners.
4. Scattered departments within a plant may find it desirable to control their expenses by means of a budget and, from such a beginning, a complete budget program may develop.
5. In some companies that manufacture a widely diversified line of products made to customer order, a sales forecast may be impractical. Internal study of past records may indicate a constant relationship between sales volume in dollars and labor dollars spent in specific departments. From an expense standpoint, in such cases, control may be obtained without either a dollar or unit forecast of sales.

Preparation of the estimates for the budget must combine the services of the accounting department and the departmental heads concerned. Initial budget estimates are then submitted to the budget committee for approval. The National Industrial Conference Board, Inc. (Budgetary Control in Manufacturing Industry) shows a schedule of budgets and budgetary routine of a large manufacturing concern that makes electrical machinery, apparatus, and supplies. The illustration (Fig. 2) demonstrates the steps by which the schedules are prepared, the responsibility for their preparation, and the time designated for submitting estimates and their approval.

ADMINISTRATION OF A BUDGET.—Proper budget administration demands that a capable budget director be charged with the responsibility and given the authority to plan and control the preparation and operation of the budget. Usually the budget director is the treasurer or controller of the business; however, he may be any executive capable of performing the task. Regardless of who is selected to administer the budget, he must have the cooperation and support of the corporate officers and junior executives. The **budget director** has primarily the following responsibilities in administering the budget of his organization:

1. Determination of the suitable budget period for his firm.
2. Provision of records of past performance, market analysis data, or forecasting data for departmental heads to aid them in:
   a. Estimating future income, sales, or expense.
   b. Estimating possible changes from seasonal, social, and economic factors.

3. Assurance that estimates are received from departmental heads at scheduled times.
4. Provision for approval of departmental budgets and their revision if necessary.
5. Compilation of a master budget that summarizes the departmental budgets.
6. Provision for flexibility of the budget program.
7. Preparation of the budget manual which specifies the approved budget procedure.
8. Leadership for securing the cooperation and coordination of the organization personnel in operating the budget.

Subject	Prepared By	Submitted To	Not Later Than	Approval
1—Orders received, sales billed, classified	District Managers	Chief Statistician	Oct. 1	
2—Orders received, ratios of gross margin, classified estimates	General Office Commercial and Decentralized Department Managers	Chief Statistician	Oct. 1	
3—Orders received, manufacturing capacity, classified summary	Chief Statistician	Sales Committee	Oct. 7	Sales—Oct. 22 Advisory—Oct. 23
4—Payroll review Under $2,600	Department Works, and District Committees, starting Sep 1 and Mar. 1	General Auditor	Oct. 15 Apr. 15	
5—Payroll review $2,600–$3,999	Department, Works, and District Committees, starting Sept. 15	General Auditor	Jan. 15	Advisory—Mar.
6—Payroll review $4,000 and above	All Managers	General Auditor	Jan. 15	Advisory—Mar.
7—Publicity	Publicity Department Managers	Advertising Council	Nov. 1	Advisory—Nov.
8—General expenses a. By accounts b. By lines of material	General Office and Decentralized Department Managers	a. Auditor of Disbursements b. Statistician	Nov. 1 Nov. 1	
9—District office expenses a. By accounts b. By lines of material	District Manager	a. Auditor of Disbursements b. Statistician	Nov. 6 Nov. 6	
10—Profit-sharing compensation—districts	District Manager	General Auditor	Nov. 6	
11—Engineering expenses	Managers of Engineering and Decentralized Departments	Vice President Engineering	Nov. 15	Manufacturing—Nov. Advisory—Dec.
12—Plant investment a. Works b. Warehouses c. Service shops	a. Managers of Works and Decentralized Departments b. Supervisor of Warehouses c. Manager Contract Service Department	Manufacturing Committee	Nov. 15	Manufacturing—Nov. Advisory—Dec.
13—Maintenance	Managers of Works and Decentralized Departments	Manufacturing Committee	Nov. 15	Manufacturing—Nov. Advisory—Dec.
14—Shipments, direct labor, indirect expense, and departmental operations	Manager of Works	Manufacturing Committee	Nov. 15	Manufacturing—Nov.
15—Orders and expenses, principal sales offices	Statistician	President	Dec. 20	
16—Profit-sharing compensation—district summary	General Auditor	President	Dec. 20	
17—Classified profit and loss	Statistician	President	Dec. 20	
18—Department profit and loss	Statistician	President	Dec. 20	
19—Summary financial operations a. Decentralized departments b. Consolidated summary	a. Managers of Decentralized Departments b. Assistant General Auditor	a. Assistant General Auditor b. President	Dec. 1 Dec. 20	
20—Cash receipts and disbursements	Assistant General Auditor	President	Dec. 20	
21—Profit-sharing compensation—all departments	General Auditor	President	Mar. 1	
22—Revised estimate, orders and expenses, if required	Managers of Districts, General Office Commercial, and Decentralized Departments	Chief Statistician	Apr. 1	Sales—Apr.
23—Orders received, manufacturing capacity, capital requirements 10-year forecast, if required	Chief Statistician	President	Mar. 1	

FIG. 2. Schedule of Budgets and Budgetary Outline Used by a Large Company Manufacturing Electrical Machinery, Apparatus, and Supplies

REVISION OF BUDGET.—A budget may need review and revision as unforeseen economic and social conditions appear. Revision of the budget may be made at monthly and quarterly periods. The characteristics of individual concerns determine the frequency of revision; general economic conditions may also necessitate an adjustment. A change in the budget estimates does not result in a complete absence of control. Most expenses vary in some degree with volume of activity. If revised estimates indicate curtailed activity, many expenses must be curtailed in a definite relationship.

In explaining the necessity for revision of budget programs, Cornell (Organization and Management) states:

> Every business activity is subject to fluctuations, some of which can be estimated with a fair degree of accuracy and some of which cannot. Budgets should be so set up that they may be readily adjusted to these changes. . . .

Master Budget

FORMATION OF MASTER BUDGET.—The master budget portrays the complete budget plan for the budget period and is dependent upon estimates of the departmental and supplementary budgets for its formation. The actual make-up of the master budget for an individual concern is determined by the extent of its budget program and activities. It represents a statement in a summary form of the estimated financial activities of the various departments and subdivisions of the organization.

The formation of a master budget is accomplished by working backward from the various detailed budgets. The accuracy and operating efficiency of the master budget are limited by the accuracy of the detailed budgets which it summarizes. Inasmuch as the master budget is based upon the detailed budgets, the latter must be scheduled for completion so as to allow enough leeway for their incorporation in the master budget. For example, if the master budget is to be completed by January 1, a deadline of December 10 may be set for completion of the detailed budgets by the departmental heads in order to give the budget director sufficient time for comparison and consolidation.

CONTENTS OF MASTER BUDGET.—The master budget for a manufacturing concern usually shows a summary and consolidation of the following:

1. Sales Budget
2. Production Budget
3. Materials Budget
4. Purchases Budget
5. Labor Budget
6. Manufacturing Expense Budget
7. Plant and Equipment Budget
8. Financial Budget

In addition, a complete master budget plan may show an estimated profit and loss statement and an estimated balance sheet. Sinclair (Budgeting) states that the master budget is expected to show:

1. Financial condition of the enterprise at the beginning of the budget period.
2. Estimated profit for the period.
3. Disposition of the estimated profit for the period.
4. Financial condition of the enterprise at the end of the period.

	Minimum	Maximum
Sales Budget:		
Estimated Sales, Product 1	$ 8,000,000	$10,000,000
Estimated Sales, Product 2	800,000	1,000,000
Estimated Sales, Product 3	1,000,000	1,200,000
Estimated Sales, Product 4	200,000	300,000
Total	$10,000,000	$12,500,000
Production Budget:		
Estimated Cost, Product 1	4,800,000	6,000,000
Estimated Cost, Product 2	560,000	700,000
Estimated Cost, Product 3	650,000	780,000
Estimated Cost, Product 4	160,000	240,000
Total	$ 6,170,000	$ 7,720,000
Estimated Gross Profits	$ 3,830,000	$ 4,780,000
Marketing Budget:		
Estimated Sales Administration	200,000	220,000
Operating of Sales Districts	1,000,000	1,100,000
Special Promotion	50,000	70,000
Advertising	500,000	700,000
Other Marketing Expense	50,000	60,000
Total	$ 1,800,000	$ 2,150,000
Administrative Budget:		
Estimated Administration Expense	150,000	160,000
Estimated Net Profit on Sales	$ 1,880,000	$ 2,470,000
Financial Budget:		
Interest on Notes and Bonds	220,000	230,000
Estimated Net Profits	$ 1,660,000	$ 2,240,000
Financial Budget:		
Federal Taxes	$ 210,000	$280,000
Preferred Stock Dividend	210,000	210,000
Common Stock Dividend	400,000	600,000
Reserve for Additions	200,000	200,000
Increase in Surplus	640,000	950,000
Total	$ 1,660,000	$ 2,240,000
Additions and Betterments Budget:		
Additions and Betterments	$ 1,200,000	$ 1,200,000
Additional Bonds to be Issued	1,000,000	1,000,000
Balance from Profits	$ 200,000	$ 200,000
Financial Budget:		
Temporary Loans (four months)	$ 150,000	$ 300,000

Fig. 3. Specimen Master Budget

FIG. 4. Profitgraph Showing Relation of Sales and Profit

PRESENTATION OF MASTER BUDGET DATA.—After the master budget is prepared, its data may be presented in either a statistical or graphic manner. There is no standard or generally accepted practice for showing the information contained in the master budget. Each concern tends to present the information according to the preference of the executives and administrators concerned.

An example of **statistical presentation** of master budget data is shown in Fig. 3, taken from Dohr (Cost Accounting), which portrays the minimum and maximum estimates of the budget items.

The **graphic presentation** of master budget data may vary considerably in its complexity. A relatively complex presentation is shown in Fig. 4. This device was developed by Knoeppel (Profit Engineering) and is used to present a picture of results, and to call attention to the "break-even" point below which a business operates at a loss. Other more simple charts may be used effectively by management to show basic data and serve as a guide in budgetary planning and control.

Production Budget

PURPOSE OF PRODUCTION BUDGET.—The production budget serves production management in planning and controlling manufacturing operations. It is prepared to show:

1. Estimated volume of production for the budget period to meet:
   a. Anticipated sales requirements.
   b. Desired inventory requirements.
2. Productive capacity of the plant facilities.
3. Cost of operations.

Although a production budget is prepared to show expected manufacturing operations for the full length of the budget period, it is broken down into monthly and weekly periods for more effective use in leveling production. By maintaining an even rate of production, management can realize lower unit costs, stabilized employment, and more efficient

PRODUCTION BUDGET

FOR MONTH OF JANUARY 19—

NAME OR SYMBOL OF ITEM	INVENTORY BEGINNING OF MONTH		PRODUCTION		SHIPMENTS		INVENTORY AT END OF MONTH	
	Estimate	Actual	Estimate	Actual	Estimate	Actual	Estimate	Actual

Fig. 5. Form for Production Budget

utilization of plant capacity. A typical production budget is shown in Fig. 5, taken from Cornell (Organization and Management), and a master production schedule in Fig. 6.

MASTER PRODUCTION SCHEDULE .... QUARTER						
Model No.	Name and Design No.	Period .... to..		Period .... to		Total
		Daily	Week	Daily	Week	
21	....					
30	....					
65	....					
74	....					
Total	....					
800	....					
820	....					
830	....					
840	....					
Total	....					
E2	....					
E4A	....					
E4B	....					
E5	....					
E5M	....					
Total	....					
Grand Total	....					

Size of form approximately 17" x 14". Plain paper. Hand ruled as required. Prepared by production department showing estimated production for each of four quarters, and accumulated totals.

FIG. 6. Specimen Form for Master Production Schedule

PRODUCTION BUDGET BASED ON SALES FORECAST.—Preparation of the production budget is based primarily upon data obtained from the sales budget and intelligent forecasting. However, in compiling the production budget from the sales forecast, inventory estimates must also be considered. The production budget is the first of the manufacturing budgets prepared, and upon its data, the materials, purchase, labor, manufacturing expense, plant and equipment, and auxiliary budgets are established. Some of the factors which must be considered in translating a sales forecast into a production program and production budget are:

1. Availability of adequate production facilities required as shown by a study of standard operation analyses of all products made.
2. Length of production process required to make products desired.
3. Present and desired inventory position.
4. Possibilities of leveling production by producing stock items in otherwise dull periods.

5. Possibilities of revising and combining processes in making different products.
6. Determining the least unit cost by producing products in economic-sized lots.

PREPARATION OF THE PRODUCTION BUDGET.—Preparation of the production budget is accomplished by adjusting the estimated sales and inventory requirements with plant productive capacity. McKinsey (Budgetary Control) gives the following steps necessary for preparing and enforcing a production budget:

1. Preparation of **sales budget:**
   a. Sales estimates are prepared by sales units.
   b. These are revised by the general sales office.
   c. They are then forwarded to the production department where a comparison is made between the requirements of sales estimates and the production capacity. If the production department thinks revisions are necessary, these are shown on the sales estimates.
   d. Estimates as approved by the production department are forwarded to the budget committee for final revision and approval. This committee will decide any differences which may exist between the programs of the sales and the production departments.
2. Preparation of **finished goods budget:**
   a. Estimate of finished goods requirements prepared from the sales budget by the production department.
   b. This estimate is forwarded to the budget committee for its consideration and approval.
   c. After the estimate of finished goods is approved by the budget committee, it is enforced by the production department by means of the balance-of-stores records operated under maximum and minimum standards.

PRODUCTION BUDGET AND PRODUCTION CONTROL.—The production budget may be used by the production department as a master plan for manufacturing activities. The objectives of the production department are to produce products of the right kind, of the right quality, at the right time, at the lowest unit cost. The following steps are essential to accomplish this:

1. The production budget must be prepared and approved.
2. The production program must be planned in accordance with budget objectives.
3. Proper production control procedures must be established and maintained to assure productive operations being in conformity with the planned production program.

Essential **production control functions** for coordinating manufacturing activities with the budget plan are:

1. Production preparation to assure that materials needed will be on hand and the proper machine capacity will be available to process them.
2. Proper routing of work to realize maximum utilization of plant facilities and capacity.
3. Production scheduling to show when and at what rate the manufacturing operations will take place.
4. Proper dispatching of work so that it will enter into the production process at the correct time to meet budget requirements.
5. Proper inspection of work so that management will be assured of the right amount and quality of product at specified times.

Lansing describes the development of methods used by his company to control production through the budget (Fact. & Ind. Mgt., vol. 75):

Running records are kept of stocks of goods and placed under the production manager who is responsible for adequate protection of all sales districts without overstocking. With his yearly and current sales quotas before him coupled with charted factory capacity, he is able to translate sales quotas into production schedules. Irregularities between sales schedules and production were gradually ironed out. Control mechanisms were set up, better statistics were developed, and control information was presented as quickly as possible after actual events had transpired. Reports showed monthly sales by commodities, by quantities, amount and average sale price for each county, each city over 25,000, and each state and sales district. The production manager and sales manager, through frequent conferences, discussed proposed changed sales plans, changing business conditions, etc., that would have a bearing on production plans.

Scheduling Procedure for Production to Stock.—Production scheduling procedure of one company, reported in a study of the Policyholders' Service Bureau of the Metropolitan Life Insurance Co. (Budgeting Manufacturing Operations), gives an example of a successful attempt to prepare and control a manufacturing program.

Prior to the beginning of each new year, an **estimate of expected sales** for the entire company in terms of tons by product classes is figured on the basis of past performance and the general economic conditions of the country. This tonnage is split among the four works and schedule of tonnages submitted to each of the works managers. Before the beginning of each quarter, sales are reestimated for the succeeding six months. Desirable inventories at the end of the period are established and production schedules authorized. With these master schedules as a guide, each works manager prepares a definite production schedule for the coming month.

At the . . . . works this schedule is converted into production totals for the various departments and the requisite man-hours are calculated. Then each department is allotted a **definite budget of man-hours** which are to be converted into a given number of tons of product. In setting quotas every attempt is made to have constant control over work in process so that the inventories of such work may be kept at the lowest possible level. The factors by which tonnages are figured in man-hours are the result of several years of careful research. A constant check on output against budgeted quotas has led to profitable economies.

The following method is used in figuring **labor and production quotas** and controlling the in-process inventory:

1. On the 15th of each month the planning department, with the approval of the works manager, issues a production schedule. This schedule gives only the tonnages by classes that it is desired to have go into finished stock. The schedule contains production figures in each class for the maximum production month, the capacity production year, the actual production, and percentage of schedule for the previous month and the schedule for the present month with the percentage of capacity required.
2. On the 16th of each month the accounting department furnishes the actual inventory figures of all work in process by classes as of the first of the month. At the same time a report of the actual production by classes of each department is made up.

   Upon receipt of this information it is possible to figure the estimated inventory as of the first of the succeeding month and by this means start only such tonnages in the primary departments as

will, when processed, equal the standard work in process figures. This makes possible, (a) an approximately constant amount of work in process, (b) the securing of a cost which has not been affected by a fluctuating work in process.

3. Having received the schedule, it is first necessary to break it down and determine how much tonnage of each class of goods will go through each department. To do this, a chart has been set up giving factors to apply to finished stock tonnages. The tonnages in the foundries and forge shops are adjusted to give the desired work in process inventory referred to above.
4. With the tonnages of each class for each department thus determined, this figure is multiplied by the number of hours it takes each department to produce a ton of each class of goods. The number of hours per ton has been determined through experiment. A deduction is made to allow for expected progress once a year when these hours are revised. The figure stays intact for the ensuing year.
5. The number of hours having been determined, this figure is divided by the number of hours in the month that each department will work. This gives the number of men needed not including absentees. A percentage allowance is added to take care of absentees.
6. By dividing the total tonnage to be produced by the number of working hours in the month, the production desired per working hour is secured. This is then multiplied by the number of hours in the day to get the daily tonnage quotas.
7. All of this information is sent to the executives on the production and labor quota form. The daily quota is put on the production quota form, one copy is given to the foreman, and one is kept in the general superintendent's office.
8. Daily the foremen report the tonnage produced and the total for the month to date on the daily tonnage report. By this it is possible to tell daily just how production is progressing.
9. Daily each foreman reports to the employment department the number of people working and absent. This information is correlated by the employment department and forwarded to the executives on the daily force report.
10. Monthly the accounting department makes up the departmental expense analysis. This gives complete information as to the quotas and hours assigned and actually used, together with the expense per ton.

Leveled Production.—One of the objectives of the plan outlined above is the regularization of production and employment. Another company, as reported by the same source cited above, desired to obtain following **results in planning production:**

1. Maintenance of an even rate of production per working day with due allowance for reduction in capacity during the summer vacation months.
2. Maintenance of an even rate of shipment from the factory per working day by varying shipments to branches in inverse proportion to the seasonal variations in the demands of other customers.
3. Maintenance of adequate stock at all times and at all distribution points to render proper service to customers.

To attain these objectives, the sales for any 12-month period are estimated to be the sales for the 12-month period just closed, plus or minus the trend as indicated by a comparison of the 12-month period just closed with the 12-month period that closed one month previously. The production during the balance of the year must be the number of units which, when added to the present stock, will permit sales equal to the

estimate and leave a carefully determined stock on hand at the end of the year. The number of units to be produced during the current month will bear the same relation to the total production required for the balance of the year as the number of working days in the current month bears to the number of working days in the balance of the year. The final quota is the figure so determined plus a percentage adjustment during nonvacation months and minus a percentage adjustment during vacation months. The planning department supervision attains these production quotas with practically no deviation.

Special Order Production Scheduling.—Production of this type is of two general classes:

1. Special orders requiring special production work in all or substantially all operations.
2. Special orders requiring a minimum of special work, the individual requirements of each order being found in minor variations requiring a small amount of retooling or in the operations required near the completion of the product.

Many times so-called "special" order businesses can find considerable aid in budgeting by forgetting the unit of product as a forecasting base and searching out internal factors that can serve as a common basis of measurement of practically all goods produced. This is illustrated by Shafer (Mfg. Ind., vol. 13), who outlines a plan of budgeting production. In translating the sales budget in dollars into workable data for the manufacturing division, the variety of products requires the latter division to work back from percentages of manufacturing cost to sales that experience has shown to be true. The manufacturing budget, therefore, is based largely on demonstrated relationships. Reconciliation of the production schedule with the budget is made monthly. On the first of each month, the president or general manager, by studying unfilled orders on hand and actual month's commitments, estimates what the sales will be for the month as well as for the next two months. The production department is advised of this amount which in turn calls for expenditures in labor, expense, and material as per the budget. The production department at first works independently of the budget and lays out a production schedule for each product in line with conditions of stock, customers' commitments, and estimate of future sales as given on the first of each month. In the preparation of the manufacturing schedule, as laid out by the production department, analysis is made of the parts making up the schedule and a departmental machine-hour analysis is prepared. To be able to divide the schedule into man-hours, the standards department has records of standard production hours per 100 pieces for each operation for each part making up the assembled units. This applies to such work as is done in the machine shop and other work such as assembling and testing, buffing, plating, and enameling.

It is possible to figure **productive labor for each department** necessary for the production schedule and finally to compare this with the amount allowed by the budget. When such an analysis is made, it is possible for the production department to give the financial department its estimate of the payroll and material cash requirements for the month. Scheduling starts on the 15th of the previous month which makes it possible to furnish orders to be issued, and manufacturing to start on the 1st of every month.

The above analysis is made on a labor- or man-hour basis. A similar plan on a bulk basis is described by Flett (Fact. & Ind. Mgt., vol. 80):

1. Operations are carried on a 13 four weeks' period basis.
2. Every item is manufactured 13 times a year or some multiple thereof.
3. Orders are analyzed by units as received and summarized figures deducted from stock cards.
4. There are 13 production centers each turning out groups of similar or allied products and using similar equipment.
   a. There are approximately 30 items made in each center.
   b. Each item is made at least once in each four weeks' period.
   c. Previous records are used to show number of hours needed to run each product which, compared with hours available, 176 per period, shows how the center will run.
   d. Once sequence of operations is set, it is not varied so that same product is always made on same day.

The forecast used as a basis of **production scheduling** is developed from past records by taking into consideration such changes as should result in different experience in the future. Manufacturing orders are drawn up ten weeks in advance on the basis of such a forecast. For example, assume that it is desired to schedule production of glass cleaner for the fourth period. It is now the middle of the second period. The record for the fourth month of the preceding year shows that 8,000 receptacles of this cleaner were sold. Business this year is, generally, 25% ahead of last year. This percentage of increase, applied to sales of this product, would indicate a sale of 10,000 units. The records show that 12,000 pieces will be used between the middle of the second period and the start of the fourth period. However, since the fourth period falls during the spring "housecleaning" time, it is decided to use a certain "special offer" which previous experience shows sells 20,000 extra pieces. These, added to the previously determined needs, show that 42,000 pieces are required. By deducting the number of pieces on hand, the number which the manufacturing department must supply is found.

This requirement is translated into gallons and since 80,000 bottles represent 10,000 gallons, 42,000 bottles would represent 5,250 gallons. The production manager now inserts a flag on the "glass cleaner" card in the file which informs the stenographer that she is to write the production order. By reference to a master formula book, she is able to ascertain the materials required for 10,000 gallons. She translates this requirement into the amount necessary for 5,250 gallons. On a detachable portion of the order she also indicates the number of containers, caps, and labels required. This section of the order is sent to the assembly department.

The filled out order then goes to the following departments:

1. Purchasing.
   a. To insure the availability of materials.
   b. Order is held here until materials have been assembled and the exact location of the batch of materials in the stockroom is noted on the order form.
2. Cost.
3. Manufacturing.

A record of pieces made each day shows pieces per worker as well as pieces for stock control purposes. Management feels safe in assuming

that the law of averages will hold true in dealing with millions of pieces. If, for example, the records show that 51 girls produce 68,000 pieces, each girl would have handled 1,334 pieces daily. If the schedule calls for 1,226,000 pieces during a four-week period, still four weeks away, it is known that 42 girls will be needed. Working under this plan the company doubled its production in eight years.

Materials Budget

PURPOSE OF MATERIALS BUDGET.—Following the establishment of the production budget, the materials budget is prepared for the budget period. Materials used are either direct or indirect. The latter class is usually budgeted as a part of overhead. The former is handled through a materials budget which shows the quantity and quality of each kind required to maintain the planned production schedule. The purposes in preparing a materials budget are:

1. Accurate determination of the materials required to meet the production program for the budget period.
2. Making possible the procurement of materials by the purchasing department coordinated to meet the production schedule. This involves the study of markets, securing quotations and placing orders.
3. Allowing those in charge of finances to plan for disbursements required for materials.
4. Providing the budget committee with a statement of financial requirements of one of the largest cost elements.
5. Supplying data for the preparation of the estimated financial statements.
6. Proper provision for quick corrective action in the event materials budget schedules do not adequately provide for actual production requirements.

PREPARATION OF MATERIALS BUDGET.—Usually the head of the production organization is responsible for the preparation of the materials budget because of its close relationship with the production budget. Cooperating with him in its preparation are the cost accounting department, engineering division, and stores department. Ordinarily the materials budget must be prepared well in advance of the budget period. It may be established as soon as estimates are available for materials requirements. With standardized materials requirements at hand, the only major problem necessitating solution is that of price. Usually it is the function of the purchasing department to give an opinion with reference to prices.

McKinsey (Budgetary Control) presents a suitable form of materials budget (Fig. 7). This is used where the budget period covers three months but can be made adaptable to longer periods simply by adding sets of monthly columns as required. Opening inventory of the first month is the same as closing inventory of the previous period and is an estimated figure based on the forecasted desired inventory position at that time. Estimated purchases are determined on basis of planned material requirements plus any desired increase in closing inventory or minus any planned shrinkage in inventory. Columns dealing with disbursements covering purchases of this month and previous month give information, in convenient form, for use of the treasurer and budget com-

MATERIALS BUDGET															
ITEMS	FIRST MONTH					SECOND MONTH					THIRD MONTH				
	Inventory Beginning	Estimated Purchases	Estimated Inventory at End	Estimated Disbursements for Purchases of Previous Month	Estimated Disbursements for Purchases of Current Month	Inventory Beginning	Estimated Purchases	Estimated Inventory at End	Estimated Disbursements for Purchases of Previous Month	Estimated Disbursements for Purchases of Current Month	Inventory Beginning	Estimated Purchases	Estimated Inventory at End	Estimated Disbursements for Purchases of Previous Month	Estimated Disbursements for Purchases of Current Month

FIG. 7. Form for Materials Budget

DIRECT MATERIAL REQUIREMENTS BUDGET From__________ To__________								
Commodity	Specification No.	Unit	Estimated Monthly Requirements					
			January	February	March	April	May	June
A........								
B........								
C........								
D........								
E........								
Etc.......								

Fig. 8. Form for Materials Budget

MATERIALS BUDGET

Names of Cigars Manufactured	Anticipated Sales for the Year	Estimate of Materials Required (Grades of Tobacco) 1	2	3	4	5
A	1,000 M	1,000 lb.		500 lb.		250 lb.
B	2,000 M		2,000 lb.		750 lb.	500 lb.
C	3,000 M			3,000 lb.	900 lb.	750 lb.
D	4,000 M			-	-	-
E	5,000 M	-	-	-		
Total pounds required for anticipated production..		M	N			
Estimated cost, including taxes, etc.		$ O	$ P	$	$	$

	Grade #1 Pounds	Grade #1 Value	Grade #2 Pounds	Grade #2 Value	Etc.
Inventory, December 31, 19—					
Purchases necessary to meet anticipated production requirements					
Material requirements	M	O	N	P	
(as per above schedule)					

The pound figures in the first schedule are based on experience. Standard material costs based on these schedules are used in costing the sales.

Fig. 9. Materials Budget for Cigar Manufacturing

mittee in visualizing needed funds for materials. Information on disbursements for purchases of former periods should come from accounting department's unpaid invoice or voucher file, while data on present period must constitute an estimate in the light of planned buying terms.

Figs. 8 and 9 illustrate a direct material requirements budget, and a special materials budget for cigar manufacturing. In the latter case, budgets and production needs are prepared for a year in advance. The reason for this is that tobacco requires a long aging process and manufacturers must carry sufficiently large inventories to insure an adequate supply of properly aged tobacco.

DETERMINING MATERIALS REQUIREMENTS.—Material requirements can usually be subjected to a large amount of engineering analysis so that quantities used for each of the main products manufactured can be determined. Well-organized cost accounting departments maintain records that disclose material requirements of every item, or of the main items, of product made. They also provide master records showing all items on which a given material is used. If such a plan of standardized material requirements is not in use, the problem of material budgeting is more complicated. Some possibilities of approach are:

1. If materials used are relatively few, an examination of past records may yield valuable facts. If a job-order cost system has been used, this examination may be supplemented with data gleaned from such cost records.
2. Valuable ratios may be found between material requirements and volume of production in sales by studying past periods.
3. Even though products made may vary, they may be reduced to a common base such as tons, and physical units of the major items of material be related thereto.

Possibilities of developing a satisfactory materials budget depend upon **degree of standardization** and recording of standards in an orderly fashion. Ideally it is best to translate planned production into materials requirements through the use of standard material requirements records.

In this connection the Policyholders' Service Bureau of the Metropolitan Life Insurance Co. describes the procedure of a shoe manufacturer in budgeting materials (Budget Suggestions for Shoe Manufacturers):

> We allow a certain number of feet of upper leather for each pattern size and width cut and demand that our cutting department keep within the allowance or budget for same. The same thing is applied to trimmings and linings except that on linings our allowance or budget is in yards or fractions thereof. Sole leather material allowances or budgets are on a money basis; otherwise, the same as upper leather. These allowances for budgets are in reality predetermined costs based on past experience and continuous tests made to discover new methods and ideas of salvaging materials. They are readjusted as necessary at the start of each season unless radical changes in conditions warrant a change during a season.

Budgets for the other classes of material are set up on a similar basis.

INVENTORY CONTROL AND MATERIALS BUDGET.—The efficient control of inventories is one of the major problems of most manufacturing concerns. Unless a mechanism is established to coordinate the supply of raw materials with the manufacturing process requirements, the materials budget loses much of its intended effectiveness

in helping to lower costs and meet delivery dates. The usual method of controlling inventories is by a suitable form of record which shows the physical movements of materials in and out of stock. Such a record should show at any period of time, for each item of raw material, the amount on hand, the amount received and issued, the amount apportioned for production orders which have been issued but on which material has not been requisitioned, the reorder point, the amount on order, and the quantity to order. The particular form in use will be dependent upon conditions surrounding the specific business under consideration.

Proper materials control assures a manufacturing concern:

1. Adequate raw materials on hand for planned production program.
2. Minimum expense incurred by rush shipments.
3. Minimum capital investment in raw materials inventories.
4. Current information concerning the company's inventory condition to facilitate managerial planning and control.
5. Customer satisfaction in meeting delivery dates of manufactured goods.
6. Proper salvage of scrap and waste materials.

MATERIALS BUDGET REPORTS.—Increased turnover and better inventory balance, with consequent increase in usefulness of the dollars invested in inventory, are aims of every material budget. Frequently studies preparatory to installation of a budget reveal unbalanced inventory conditions which would have gone unnoticed had not the budget been started.

PERIODIC REPORT ON MATERIALS BUDGET							
ITEMS	Estimated Purchases	Actual Purchases	Per Cent of Increase or Decrease	Estimated Inventory	Actual Inventory	Per Cent of Increase or Decrease	COMMENTS

Fig. 10. Periodic Materials Budget Report

A report to show how closely the materials budget is being met is illustrated in Fig. 10 taken from McKinsey (Budgetary Control). While the columns are self-explanatory, the report must be read in the light of changes in the production budget which are reflected on the production budget report. Changes in the materials budget for the remainder of the period can be made only through a joint study of these reports.

Aside from features of the materials budget having to do with desired inventories, use of materials in production is an important item to be watched. Establishment of material standards as to use and a knowledge of the physical volume of goods make possible a check on the efficiency in the use of materials. Where a complete standard cost system is in operation, reports showing such factors are common. Since materials utilization is one of the tasks of operating men, budget reports covering it are usually combined with other factors under control of the same

man. Such a report would show the allowed material cost for volume of actual production compared with actual cost of actual production. The loss or gain from standard would then be analyzed into price and use factors.

Purchase Budget

PURPOSE OF PURCHASE BUDGET.—The purchase budget portrays the specific purchases that must be made of raw materials, supplies, parts, and equipment to coordinate with the materials and production budgets. Proper establishment of the purchase budget enables:

1. The purchasing department to have on hand materials, supplies, parts, and equipment, of the desired quality and quantity, at the time specified by the materials budget to provide for the needs of the production program.
2. The head of the financial organization to know the purchase requirements and plan for probable expenditures at the time the budgets are being prepared.
3. The amount of investment in inventories to be kept at a minimum consistent with purchasing under favorable market conditions.

PREPARATION OF PURCHASE BUDGET.—After the production and materials budgets have been established, certain estimates for the purchase budget must be made for the budget period as follows:

1. Cost of direct materials required.
2. Cost of indirect materials and supplies for operating and administrative departments.
3. Cost of capital expenditures for machinery and equipment.

The responsibility for the purchase function varies according to the size and organization structure of a business. Whether the purchasing function is set up as a separate department headed by a purchase officer, or whether the purchase function is integrated with the production department, the person charged with the purchasing responsibility must obtain the basis of the purchase budget by combining the estimate for direct materials with the estimate for indirect materials and supplies. The net requirements for any given item for a given month or period of time are found by adding the production requirements to the amount desired to have on hand at the end of the month or period and subtracting the amount on hand at the beginning of the month or period. Typical forms for the purchase budget are shown in Figs. 11, 12, and 13, taken from Sinclair (Budgeting).

PURCHASE BUDGET
For Month of January, 19—

Commodity	Requirements for Products	Inventory Beginning of Month	Inventory End of of Month	Net Required		Estimated Cash Disbursements for Purchases
				Vol.	Value	
Pig Iron	500 tons	1,300 tons	1,000 tons	200 tons	$12	$ 2,400
C. R. Steel	300 tons	100 tons	500 tons	700 tons	60	42,000

Fig. 11. Purchase Budget

PURCHASING FORECAST From ________ To ________															
Commodities	Specification No.	Unit	Production Forecast Requirements (Quantities) (A)	Estimated Inventory at Close of Period (Quantities)			Inventory at Beginning of Period (Quantities)			Anticipated Purchases			Actual Purchases		
				Raw Materials	Work in Process	Total (B)	Raw Materials	Work in Process	Total (C)	Quantities (A + B − C)	Estimated Prices	Estimated Amount	Quantities	Prices	Amount

Fig. 12. Form for Purchase Budget

MONTHLY PURCHASES BUDGET										
ITEM	FIRST MONTH					SECOND MONTH				
	Inventory Beginning	Estimated Purchases	Estimated Inventory at End	Estimated Disbursements for Purchases of		Inventory Beginning	Estimated Purchases	Estimated Inventory at End	Estimated Disbursements for Purchases of	
				Previous Months	Current Month				Previous Months	Current Month

Fig. 13. Form for Purchase Budget on Monthly Basis

PLANNING THE PURCHASE BUDGET.—To prepare the purchase budget, it is necessary to plan it in accordance with requirements for the budget period. Effective planning depends upon the availability of information as to the presence or absence of those factors influencing the maximum and minimum standards for materials.

In many companies the item of **inventories** is one of the major assets of the business. There is a universal desire to decrease the funds involved in inventories by turning over the materials inventory more rapidly. Effective planning of the purchase budget can aid greatly in accomplishing this result.

Inventory Turnover.—In manufacturing, turnover of inventories means the number of times an item of materials is used during a given period. For convenience, the dollars invested in the stock rather than the units are used in this computation. If, for example, a given company has an average monthly investment in raw material inventory of $100,000 and it uses $500,000 worth of material in making its yearly output, it would be said to have a "turnover" of five. Assuming that material costs were relatively a large part of total cost, it might well follow that investment in inventory would be relatively high. If such investment could be halved through scientifically developed control devices and aggressive follow-up, a turnover of ten would result and the company would then be able to obtain a wider margin of profit through lowered costs of carrying heavy inventories. General Motors Corp. has aggressively followed a policy of increased turnover of its investments in materials, since it establishes its budgets through a desired profit approach.

Price Forecasting.—An important phase of purchase budgeting consists of an intelligent translation of physical into financial factors, particularly in times of rapidly rising or declining prices. Some of the factors which must be considered in developing a price forecast are:

1. History and trend of price movements of major commodities used.
2. Availability of reliable statistics on supply of materials.
3. Possibility of shifting risk of price change through hedging or entering into long-term contracts containing price rise or decline guaranty clauses.
4. Relative size and strength of the particular company and the consequent ability to secure price concessions and protection.
5. Existence of unknown factors, such as weather conditions, which may cause shortages or surpluses of commodities.

PROBLEMS OF OPERATING THE PURCHASE BUDGET.—Although it may be planned that materials are to be purchased in accordance with the production schedule, many factors can complicate this desired coordination. Among them are the following:

1. Monthly materials requirements for production may not represent economically sized purchase lots.
2. Extremely favorable prices may be secured through long-term contracts, with or without provision for guarantee against price decline.
3. Some materials may have particular properties which make it desirable to purchase a season's supply when it is available.
4. There may be a lag of several weeks or months because of a long-time production process.
5. Materials may be available only seasonally while demand and production are fairly regular.
6. Supply of certain materials may be uncertain because of governmental priorities system or because of geographic sources.

Usually a purchase budget cannot be established wholly upon production and inventory requirements. Consideration must also be given to the financial condition of the company, market conditions and available sources of supply for each item, and the nature of the manufacturing operations.

Labor Budget

PURPOSE OF LABOR BUDGET.—Labor costs of a manufacturing concern entail both salaries and wages paid executive, supervisory, clerical, and operating employees. The labor budget usually includes only wages paid to workers engaged in primary productive activities, i.e., **direct labor costs.** Indirect labor costs are shown in the manufacturing expense budget. After the production and materials budgets are determined, it is necessary to estimate the direct labor costs on the basis of planned production. This is done through the labor budget to:

1. Enable the employment department to provide the employees necessary to perform the tasks outlined by the production program.
2. Provide management with an estimate of total direct labor costs for use in planning of disbursements and preparation of an estimated statement of cost of goods manufactured and sold.
3. Provide data to assist management in stabilizing employment and minimizing labor turnover.

LABOR BUDGET AND PRODUCTION AND LABOR POLICIES.—One of the main purposes of the labor budget in many concerns is the leveling of the fluctuations in employment and stabilizing the number of employees on the payroll. This is especially typical of a company that depends upon quality and skilled labor as its main selling argument. Hence, good labor management demands that extreme fluctuations in size of working force should be avoided as much as possible. Labor turnover should be held to a desirable minimum. To accomplish this, production must be planned accordingly so that it will take place as evenly as possible for the budget period and aid in assuring labor steady employment and a fair annual wage.

In planning production to this end, there comes the question of **economic-sized manufacturing lots.** Set-up costs need to be spread over as many units as possible without overstocking. Routinized production gives best results on infrequent but relatively long runs. Production costs may be lowered if plans are made to utilize plant and machine capacity as fully as possible. Because of these factors which influence the labor budget, the production organization should have a major portion of the responsibility in preparing the labor budget and determining the labor policies.

ESTIMATING LABOR REQUIREMENTS.—Preparation of the labor budget necessitates estimating labor requirements in terms of some physical factor such as man- or machine-hours, and also in terms of the financial factor of dollar labor costs. Ability to provide this estimate depends, to a large extent, upon availability of adequate labor records based on past performances and scientific study of labor operations. Much depends, also, upon the method or methods of wage payment in

use. Among methods of determining labor requirements are the following:

1. **Analysis of operations** performed and number of labor-hours consumed in making each product. Application of data so developed to the production budget would yield required labor-hours which, in turn, could be converted into number of men required.
2. **Study of past records** may show a more or less constant relationship between production volume and machine- or labor-hours used. This can be done both for labor as a whole and for each class of labor and for each class of product.
3. **A usable dollar estimate** can be secured from a study of past labor costs per ton, yard, square foot, or other unit common to all products, and application of that unit cost to production units planned for the coming period. This would be particularly useful under varying volume and hence where labor hours were not of great importance as a forecasting factor.
4. **Standard labor costs** may have been set for all work of a recurring nature. These costs can be readily applied to production as budgeted to obtain a budgeted standard cost.

Selection of any one or a combination of the above aids in estimating labor requirements depends upon availability of necessary data. More and more businesses have increased their information relative to this phase of production work with the growth in installation of incentive plans and acceptance of ideas of measured performance as a pay base.

PREPARATION OF THE LABOR BUDGET.—After labor requirements, as developed from a consideration of the production budget, have been tempered by factors of labor policy, the labor budget can be prepared, usually by the production department, and extended as to cost by the personnel or cost department. Sinclair (Budgeting) explains three general methods whereby the labor budget may be constructed:

1. By analysis of product.
2. By analysis of processes.
3. By analysis of labor cost.

The number of man-hours required to make the scheduled product may be obtained from an **analysis of the product** planned by the production schedules from the production budget. This analysis may be made from either time standards, from time and motion studies, or reliable records of past performance. Each item of the product is analyzed to determine the amount of each kind of labor required to produce it. When all items have been studied, the totals will be the amount of labor or number of man-hours of each class and grade required to produce the product in accordance with the production program.

Where it is more convenient to determine production in terms of machine-hours, an **analysis of processes** may be used. With this method the budget of machine capacity is used to determine the number of machine-hours necessary to make the product scheduled in the production program; from this an estimate of labor-hours is established.

An analysis by means of **labor cost** is used:

1. Where cost control is by means of a system of standard costs.
2. Where either analysis by product or process seems inadvisable.

LABOR BUDGET

Department	Amount Last Period	Average Amount Last Four Periods	Estimated Amount for Present Period	Estimated Production for Present Period	Average Production for Last Four Periods	Distribution		
						First Month	Second Month	Third Month

Fig. 14. Form for Labor Budget

________Co. ________Dept.
________Division ________Section.

PAYROLL BUDGET
(Expressed in Numbers and Dollars)

Approved ________________
Section Head

	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	(Previous Year) 9 Mos. Actual 3 Mos. Estimate		Preliminary Estimate		% Change (+ or −)		Approved Budget		% Change (+ or −)	
	Number	Value	Number	Value	Col. C from Col. A	Col. D. from Col. B	Number	Value	Col. G from Col. A	Col. H from Col. B
Executive										
Supervisory										
Technical										
Sales										
Clerical										
Labor:										
Productive (Direct)										
Productive (Indirect)										
Other										
Total Labor										
Total Section										

Fig. 15. Payroll Budget Form

Page ___
PAYROLL BUDGET
(Expressed in Numbers and Dollars)

_______ Company
_______ Division
_______ Department

Approved:
_______ Pres.
_______ Dir. Hd.
_______ Dept. Hd.

	*Budget		January		February		March		December	
	Number	Value	Number	Value	Number	Value	Number	Value	Number	Value
Executive										
Supervisory										
Technical										
Sales										
Clerical										
Labor:										
Productive (Direct)										
Productive (Indirect)										
Other										
Total Labor										
Total										

* Designate figures as preliminary or approved.

FIG. 16. Monthly Payroll Budget

Under a system of standard costs, the labor cost of producing a given volume of product is determined and transposed into estimates of time from schedules of wage rates. Where standard costs are not used, labor costs may be obtained by applying the ratio of labor costs to total costs from past experience. The amount can then be transposed into man-hours.

Form for Labor Budget.—One form of the labor budget is shown in Fig. 14, taken from McKinsey (Budgetary Control). Aside from the data on labor cost, ready comparison is offered between amounts of payroll and production in the last period and an average over the last four periods. This form is used to transmit the labor budget by departments to the budget committee. In building up these departmental totals more detailed consideration would be required to specific classes of labor within the department.

For this purpose a form (Fig. 15) presented by Grassmuck (A.M.A. Annual Convention Series, No. 32) is useful. This schedule provides data as to both number of employees and wages paid, both for the preliminary estimate and the approved budget, compared with results of previous year, three months of which are necessarily estimated at the time the budget for the new year is being considered. A similar form is used to bring together all payroll and labor data for all departments.

From these data the **monthly payroll budget** (Fig. 16) is developed, again showing by departments the number of employees and total wages paid each month. This schedule bears the approval of the president, division head, and department head.

LABOR BUDGET REPORTS.—Frequently there occurs a variation between budget estimates and actual performance of direct labor which indicates variations in labor costs. These are analyzed as to time (efficiency) and rate variances.

Brinkman (Mfg. Ind., vol. 16) describes the introduction of a complete plan of labor control as follows:

Use of budgetary control in our factory is the outgrowth of the use of a simple and complete cost control and record system. Outgrowth was result of a gradual improvement in factory cost system so that it functioned more and more as a means of predicting performance costs and showing results of actions by foremen on high cost items, and less as a historical record of performance. The use of labor cost and performance records, covering efficiency of output and quality of workmanship as a means of measuring departmental and factory efficiency in the computation of premiums to executives, also has had its effect on the nature of the whole control mechanism of factory operation budgets.

Job time cards are analyzed in several ways and individual record cards kept for each operator showing by weeks: perfects, imperfects, gross production, percentage of perfects, hours, basic rate per hour, basic wage, premiums, percentage of premium, time work or overtime, minimum wage, allowances, total earnings, total earnings per hour, spoilage or deductions, and style or class of work. Each week two copies of a report go to each foreman, with a copy to factory manager, showing high costs and exceptional performances with all high cost items analyzed for cause and effect. The foremen file one copy of their report and return other to factory executives, noting on this copy the action taken by the foreman on matters shown therein. This copy is used as a basis of discussion with the foreman.

Manufacturing Expense Budget

NATURE OF MANUFACTURING EXPENSE BUDGET.—The purpose of the manufacturing expense budget is to establish an effective method for planning and controlling manufacturing expenses. Proper budgeting of manufacturing expenses can reduce costs by keeping these expenses in line with changing volumes of production. Usually manufacturing expenses can be determined in advance with a fair degree of accuracy from a study of past records. Consequently, management can use the manufacturing expense budget as a device for planning and controlling this important item in manufacturing costs.

PREPARATION OF MANUFACTURING EXPENSE BUDGET.—The cost accounting department usually assembles the data and prepares the estimate of the necessary manufacturing expense for the budget period. After the complete estimate is made from the data assembled from the departmental units, it is submitted to the budget director for use in making operating plans for the organization. According to Sinclair (Budgeting), effective budgeting of manufacturing expenses involves four major steps:

1. Determining the amount of manufacturing expense necessary to produce the volume of goods specified in the production schedules.
2. Classifying the determined amount of manufacturing expense for purposes of the budget and for departmental control.
3. Construction of a manufacturing expense budget for each factory department.
4. Comparison and check of the estimated and actual expenditures for each item of the manufacturing budget.

The fourth step above involves the initiation of corrective measures in those cases where the expenditures exceed the estimates.

Expense budgets may be prepared in the following ways:

1. Use of tables, charts, or formulas.
2. Estimates by accounts.
3. Flexible budget.

USE OF BUDGET TABLE.—Whereas other items of manufacturing cost, labor, and material tend to vary with the volume of production, manufacturing expenses often have little relationship to actual volume. Some expenses which vary with production are termed variable or semivariable depending upon the degree of variability. Those expenses which remain constant are called fixed expenses. Some concerns are able to establish control over manufacturing expenses even if they find it impossible to establish a satisfactory sales and production budget. They reason that, within a given volume bracket of production, plant facilities are usually utilized in a manner to require an approximate amount of various expenses. On this basis they are able to exercise a considerable amount of control without a definite production forecast, by reducing the variable and fixed expenses to a formula, or chart or table.

An example of a budget table for factory burden is given in Fig. 17 (N.A.C.A. Bul., vol. 19). Such a table is based on the principle that burden consists of two parts: a variable part and a fixed part. The fixed

part of $1,071.42 per month represents such items as depreciation, insurance, taxes, supervisory labor, etc. The table may be used to compute budgeted overhead for any volume within the table limits. Thus, the allowed overhead or expense for an estimated production of 539,784 units is computed as follows:

Fixed charge	$1,071.42
Variable charge (539,784 × $.0108)...............	5,829.67
Total allowed expense	$6,901.09

If the actual production turns out to be only 423,744, a similar computation shows the allowed expense to be $5,647.86. By comparing this figure with the actual expense of, for example, $5,897.86, an unfavorable expense variance of $250 is indicated. The latter must then be analyzed as to causes.

(1) Units Produced	(2) Unit Variable Expense	(3) Total Variable Expense (1) × (2)	(4) Budgeted Monthly Fixed Costs	(5) Budgeted Monthly Total Costs (3) + (4)
0	$.0108	$ .00	$1,071.42	$1,071.42
50,000	.0108	540.00	1,071.42	1,611.42
100,000	.0108	1,080.00	1,071.42	2,151.42
150,000	.0108	1,620.00	1,071.42	2,691.42
200,000	.0108	2,160.00	1,071.42	3,231.42
250,000	.0108	2,700.00	1,071.42	3,771.42
300,000	.0108	3,240.00	1,071.42	4,311.42
350,000	.0108	3,780.00	1,071.42	4,851.42
400,000	.0108	4,320.00	1,071.42	5,391.42
423,744	.0108	4,576.44	1,071.42	5,647.86
450,000	.0108	4,860.00	1,071.42	5,931.42
500,000	.0108	5,400.00	1,071.42	6,471.42
539,784	.0108	5,829.67	1,071.42	6,901.09
550,000	.0108	5,940.00	1,071.42	7,011.42
600,000	.0108	6,480.00	1,071.42	7,551.42
650,000	.0108	7,020.00	1,071.42	8,091.42
700,000	.0108	7,560.00	1,071.42	8,631.42

FIG. 17. Table of Budgeted Variable and Fixed Expenses

A wire manufacturer, a large percentage of whose business is special orders, has developed a similar plan. A historical study of the costs at varying volumes gives a **key to costs expected** at similar volumes in the future. Wanner describes the company's procedure (Fact. & Ind. Mgt., vol. 76):

Manufacturing expenses are broken down into 63 separate accounts and are classified into fixed, semi-variable, and variable. Each foreman makes an estimate regarding such of these expenses as come under his control based on amount of production that would come out of his department if it were continuously busy, allowing for idleness due to physical causes. The controller's department then adds those items over which foremen have no control yet can conveniently be prorated against departmental production. Semi-variable items are largest and hence most necessary to control. Conferences are held between the controller and each foreman to determine what would happen to various variable and semi-variable items at different

levels of production using productive labor as a measure of departmental volume. From these data a series of factors is worked out from which the correct budget at any volume can be determined. Such a set of variability factors might read as follows:

DEPARTMENTAL LIST OF PER CENT VARIABILITY ON ALL EXPENSE

	Dept. 1	Dept. 2	Dept. 3
For 30% and over Increase......	.375	.540	.242
25% to 30% "	.380	.542	.243
20% to 25% "	.395	.545	.242
15% to 20% "	.405	.550	.240
10% to 15% "	.415	.555	.240
5% to 10% "	.405	.559	.245
0% to 5% "	.400	.550	.250
For 0% to 5% Decrease......	.400	.550	.250
5% to 10% "	.380	.535	.242
10% to 15% "	.370	.525	.234
15% to 20% "	.362	.520	.227
20% to 25% "	.355	.517	.222
25% to 30% "	.350	.515	.218
30% and over "	.345	.513	.215

Thus, if volume for department 1, as measured by productive labor used, is below normal by something between 15% and 20%, actual per cent deficiency multiplied by the factor .362 gives proper deduction from normal budget. If for instance, normal for department 1 is $20,000 per month, 82% of such normal activity would call for the reduction of $1,303.20, (.362 × 18% × $20,000) or $18,696.

ESTIMATES BY ACCOUNTS.—Expense budgets may be prepared on the basis of charts, or tables, or estimates may be prepared for each account. The result, when totaled, represents the estimated manufacturing expense. A form for such a budget is illustrated in Fig. 18, taken from Glover and Maze (Managerial Control).

An example of manufacturing expense budget procedure as used by a maker of musical instruments is described in Budgeting Manufacturing Operations (Policyholders' Service Bureau, Metropolitan Life Insurance Co.) as follows:

The first step is the analysis of the manufacturing department as to the amount of expense incurred during the previous year. The expense groups used by the company are as follows:

- Supervision
- Inspection
- General labor
- Overtime excess
- Reclamation labor
- Tool repair labor
- Machine repair labor
- Equipment labor
- Spoilage labor
- Supplies
- Reclamation material
- Tool repair material
- Machine repair material
- Equipment repair material
- Spoilage material

From the analysis of these accounts an average expense per accounting period is computed and placed on a form (Fig. 19). This expense schedule is sent to the foremen, who place on it their best estimate for the cost necessary for the operation of their departments for the next period. It is then returned to the cost department and reviewed item by item by the factory manager, the superintendent, the cost accountant, and the foreman of the department in question. In a conference of these four executives, all contemplated changes during the next budget period are considered and

THE SHOP BUDGET
For the fiscal year 19 .

Expense Acct. No.	NAME	Dept. 100	Dept. 101	Dept. 102	Dept. 103	Dept. 104	Dept. 105	Total
1	Executives							
2	Supervision							
3	Technical Assistants							
4	Inspection							
5	Clerks							
6	Steno's and Typists							
7	Timekeepers and Checkers							
8	Storekeepers and Assist.							
9	Truck drivers and Chauffeurs							
10	Watchmen and Gatemen							
11	Elevator Operators							
12	Janitors and Sweepers							
13	Laborers							
14	Oiling and Cleaning Mach's.							
15	Machine Set-up.							
16	Training Expense							
17	Idle Time (No Power)							
18	Idle Time (Mach Breakdown)							
19	Idle Time (Waiting for Work)							
20	Taking Inventories							
21	Vacation							
22	Sickness							
23	Military Service							
24	Maint. of Boiler							
25	Maint. of Machinery							
26	Maint. of Hydraulic Eq.							
27	Maint. of Motors and Controllers							
28	Maint. of Generators							
29	Maint. of Light Eq.							
30	Maint. of Power Lines							
31	Maint. of Pipe Lines							
32	Maint. of Pumps							
33	Maint. of Transmit Eq.							
34	Maint. of Matl. Hnd. Eq.							
35	Maint. of Storeroom Eq.							
36	Maint. of Dies							
37	Maint. of Jigs and Fixtures							
38	Maint. of Gauges							
39	Maint. of Tools							
Total	Carried Forward							

FIG. 18. Form for Shop Budget

a standard expense schedule is set up which stands intact for the budget period. These schedules are then written on a form (Fig. 20) prepared for this purpose. Five copies are made, one each for the foreman, superintendent, factory manager, general manager of manufacturing, and cost accountant.

The general factory expenses are prepared in a similar manner and placed on a standard expense schedule. The accounts and their sources of information are shown in Fig. 21. The various manufacturing expenses and the general factory expense items together constitute the total manufacturing expense. . . .

STANDARD EXPENSE SCHEDULE							
Acct. No.	Description	Average Actual Last Year	Number	Hours	Rate	Standard Amount	
						Per Period	Per Week
	Productive Labor						
1	Supervision						
2	Inspection						
3	General Labor						
4	Overtime						
5	Reclamation Labor						
7	Tool Repair Labor						
8	Machine Repair Labor						
9	Equipment Repair Labor						
10	Spoilage Labor						
	Total Labor						
51	Supplies						
55	Reclamation Material						
57	Tool Repair Material						
58	Machine Repair Material						
59	Equipment Repair Material						
60	Spoilt Material						
	Total Material						
	GRAND TOTAL						
	Fixed						
	Fluctuating						
	GRAND TOTAL						

Fig. 19. Schedule for Estimating Departmental Expense

STANDARD EXPENSE SCHEDULE								
PERIOD			TOTAL MFG. COST					
Acct. No.	Description	Hours in Standard Month	Rate		Standard Amount			
			Amount Per Hour		Per Period		Per Week	
	Productive Labor							
1	Supervision							
2	Inspection							
3	General Labor							
4	Overtime							
5	Reclamation Labor							
7	Tool Repair Labor							
8	Machine Repair Labor							
9	Equipment Repair Labor							
10	Spoilage Labor							
	Total Labor							
51	Supplies							
55	Reclamation Material							
57	Tool Repair Material							
58	Machine Repair Material							
59	Equipment Repair Material							
60	Spoilt Material							
	Total Material							
	GRAND TOTAL							
Fixed								
Fluctuating								
GRAND TOTAL								

Fig. 20. Standard Expense Schedule and Departmental Budget

A record of the products transferred from the manufacturing division to the finished stockroom is kept, divided into the cost of labor, material, and overhead. From this record, the percentage of material and labor to the total cost is determined for each budget group of product. An excellent control over departmental expense is assured through the schedules and the conferences incident to their analysis.

Account Name	Source of Information
Supervision	General Manager of Mfg.
Inspection	General Manager of Mfg.
Spoilage	Cost. Dept. Records
Payroll Department Salaries	Cost. Dept. Records
Employment Department Salaries	Cost. Dept. Records
Factory Office	Production Manager
Shop Clerks	Cost Dept. Records
Freight Hauling	Cost Dept. Records
Stockkeeping	Chief Stockkeeper
Inventory Expense	Cost Dept. Records
Free Repairs—Labor	Cost Dept. Records
Repairs to Returns—Labor	Cost Dept. Records
Suggestion Committee	Cost Dept. Records
Cost Department Salaries	Cost Dept. Records
New Tools—Labor	Chief Engineer
Factory Stationery	Prod. Manager and Cost Dept.
Scrap Material	Cost Dept. Records
Free Repairs—Material	Cost Dept. Records
Repairs to Returns—Material	Cost Dept. Records
Taxes—Inventory	Cost Dept. Records
Miscellaneous Mfg. Expense	Cost Dept. Records and Gen. Mgr. of Mfg.
New Tools—Material	Chief Engineer
Factory Traveling Expense	General Manager of Mfg.
Reclamation—Labor	Cost Dept. Records and Supt.
Testing of Finished Product	Cost Dept. Records
Supplies	Cost Dept. Records
Reclamation—Material	Cost Dept. Records
Building Repairs—Labor	Cost Dept. Records and Maint. Eng'r
Sweepers and Watchmen	Cost Dept. Records and Maint. Eng'r
Firemen	Cost Dept. Records and Maint. Eng'r
Building Equip. Repairs—Labor	Cost Dept. Records and Maint. Eng'r
Taxes—Real Estate	Cost Dept. Records
Coal	Cost Dept. Records
Building Operation Supplies	Cost Dept. Records
Building Repairs—Material	Cost Dept. Records and Maint. Eng'r
Depreciation	Cost Dept. Records
Building Equip. Repairs—Material	Cost Dept. Records and Maint. Eng'r
Machine Repair—Labor	Cost Dept. Records and Maint. Eng'r
Equipment Repair—Labor	Cost Dept. Records and Maint. Eng'r
Truck Supplies	Cost Dept. Records
Machine Repairs—Material	Cost Dept. Records and Maint. Eng'r
Equipment Repairs—Material	Cost Dept. Records and Maint. Eng'r
Taxes—Machinery	Cost Dept. Records
Depreciation—Machinery	Cost Dept. Records
Depreciation—Equipment	Cost Dept. Records
Taxes—Equipment	Cost Dept. Records
Engineering Salaries	Chief Engineer
Engineering Supplies	Chief Engineer
Gas	Cost Dept. Records
Electricity	Cost Dept. Records
Experimental Labor	Experimental Eng'r and Cost Dept.
Experimental Materials	Experimental Eng'r and Cost Dept.
Shipping Expense	Cost Dept. Records
Shipping—Miscellaneous	Cost Dept. Records
Shipping Supplies	Cost Dept. Records

FIG. 21. Schedule of General Factory Expense Accounts

FLEXIBLE BUDGET.—A flexible budget is one which provides separate expense allowances at varying levels of productive capacity (Fig. 22). The method by which a flexible budget may be planned and prepared is described in Budgeting as an Aid to Management (Policyholders' Service Bureau, Metropolitan Life Insurance Co.) as follows:

A company that originally planned its operating expenses on the assumption that it would operate at a certain rate of activity might prepare an estimate of the cost of operating at various other rates. These alternative estimates would make it possible to measure the plant's operating efficiency, even though the actual cost of operation had been influenced by unexpected changes in business volume.

There are two steps to the preparation of flexible budget estimates: first, a determination of the cost of each type of expense at various volumes of activity, and, second, the presentation of this information in a form that will be usable for budget purposes. (In connection with the first of these points, operating expenses are usually classified as fixed, semi-variable, and fully variable.)

The cost of items in the **variable expense** group, under varying rates of activity, can be figured by a simple calculation. The items in the fixed expense group, of course, have no such variation and require no computation. The determination of the cost variation of items in the semi-variable group is usually made either from engineering computations of machine performance or from a study of previous cost data.

While a thorough computation of costs under **varying rates of activity** requires considerable effort, it is usually introduced as a refinement after the budget has been established. Once accurately established, the schedules of flexible costs need be revised only when (a) wage scales are changed, (b) substantial changes occur in the general level of commodity prices, or (c) the company changes the character of its equipment or its operating methods.

After the costs under varying rates of activity have been determined for all operating expense items, it is necessary to organize and present the information in a usable form. Naturally, the most useful method of organizing the data is to follow the classifications shown on the budget. The information may be shown either in ratio form, or in actual dollars of expense; and it may be presented either in chart or tabular form.

The **ratio method** of presenting flexible budget data may be applied effecively to certain types of manufacturing. Concerns having a limited line of products or little variation in operations sometimes set up flexible budgets as a ratio of expense to sales. In other instances, the dollar cost of the various expense items at different levels of activity is determined.

The presentation of flexible budget data is often made effectively through the medium of **charts**, which show on one axis the rate of activity and on the other, the dollar or percentage cost. Curves prepared in this manner have been found useful for determining quickly the estimated reasonable operating cost at varying levels of activity. Some concerns present in tabular form a series of two or more alternative budget estimates which show the anticipated operating expense under various rates of activity. This method has also been found helpful in appraising the efficiency of the plant irrespective of the rate of output.

MANUFACTURING EXPENSE BUDGET REPORTS.—If manufacturing expenses are successfully controlled so as to conform with operating plans, there must be established checks and comparisons of the estimates and actual charges. To accomplish this, weekly and monthly comparative reports may be prepared by the accounting department for the budget director. A study of these comparative reports indicates corrective changes for departments concerned.

WORKS INDIRECT EXPENSE BUDGETS PER WEEK
FOR VARIOUS OPERATING CAPACITIES

V WORKS

A DEPT.

REVISED 1/1/— 1 WEEKS Harris FOREMAN

NO	DIRECT HOURS	1,000	1,100	1,200	1,300	1,400	1,500	1,600	1,700	1,800	1,900	2,000
	PER CENT CAPACITY	50	55	60	65	70	75	80	85	90	95	100
01	Executive Staff											
02	Foremen	35	35	35	35	35	45	45	45	45	45	45
03	Inspectors											
04	Clerical	27	27	28	28	29	29	30	30	31	31	32
	Total Superv & Cler	62	62	63	63	64	74	75	75	76	76	77
10	Guards & Gatemen											
11	Oilers, Sweep and Clean	10	11	12	13	14	15	16	17	18	19	20
12	Internal Transportation	7	7	7	8	8	8	9	9	9	10	10
13	Personnel Adjustments											
14	Idle or Lost Time											
15	Other Indirect Labor	35	38	41	44	47	50	53	56	59	62	65
	Total Indirect Labor	52	56	60	65	69	73	78	82	86	91	95
20	Fuel											
21	Sand											
22	Nails, Rods and Wires											
23	Binders and Facings											
24	Grinding & Polishing Wheels	4	4	5	5	6	6	7	7	8	8	9
25	Paints, Lubricants & Waste	5	5	5	6	6	6	7	7	7	8	8
26	Stationery & Office Supplies	1	1	1	1	1	1	2	2	2	2	2
27	Miscellaneous Supplies	5	5	5	5	5	5	5	6	6	6	6
28	Purchased Electricity											
	Total Operating Supplies	15	15	16	17	18	18	21	22	23	24	25
40	Real Estate											
41	Buildings											
42	Machinery	30	33	36	39	42	45	48	51	54	57	60
43	Motors	6	7	7	8	8	9	9	10	10	11	11
44	Semi durable Tools & Inst.	90	99	108	117	126	135	144	153	162	171	180
45	Internal Transp Equip t											
46	Carting Equipment											
47	Furniture and Office Appl											
48	Flask Equipment											
49	Patterns											
50	Miscellaneous Equipment	4	4	4	4	4	4	4	4	4	4	4
	Total Maintenance	130	143	155	168	180	193	205	218	230	243	255
60	Re arrangement of Equip't											
61	Postage											
62	Telephone											
63	Telegraph and Cable											
64	Inventory Adjustment											
65	Employees' Welfare	2	2	2	2	3	3	3	3	3	3	3
66	Liability Insurance											
67	Dues and Subscriptions											
68	Gratuities											
69	Rentals											
70												
71	Miscellaneous Expense	4	4	4	4	4	4	4	5	5	5	5
	Total Sundries	6	6	6	6	7	7	7	8	8	8	8
	Total Above Charges	265	282	300	319	338	365	386	405	423	442	460
80	Depreciation											
81	Insurance											
82	Taxes											
	Total Fixed Charges											
	Total all Charges											

FIG. 22. Flexible Budget

Several basic essentials must be observed in accomplishing **successful control of manufacturing expenses** through the budget:

1. A clear distinction must be made between fixed and variable expenses.
2. A careful distinction must be maintained between controllable and uncontrollable expense.
3. Expenses must be budgeted through cooperation of foremen whose duty it will subsequently be to live within the budget.
4. Comparative reports must be issued promptly and must be prepared in a manner most easily understood by foremen reviewing them.
5. The flexible principle of allowing for variations in production volume must be thoroughly understood and used.

An example of a report comparing actual operations with the budget is given by Alford (Principles of Industrial Management) and shown in Fig. 23.

Weekly Budget Comparisons—Operation with Budget

Items of Operating Cost	Monthly Budget Allowance	Expended to Date	Daily Budget Allowance	Average Expended per Day to Date
Direct Labor...........	$24,000	$ 7,944	$1,090	$1,135
Non-Variable Overhead.	17,600	5,600	800	800
Indirect Labor.........	9,000	3,392	450	484
Stores	3,850	1,503	175	215
Compensation Insurance	700	230	30	33
Fuel Oil..............	8,800	2,817	400	402
Coal..................	2,750	779	125	111
Sundry................	5,300	1,835	240	262
Total Overhead........	48,000	16,156	2,220	2,387
Total Manufacturing....	72,000	24,100	3,310	3,187

Estimated Production for Month $200,000 Per Day $9,100
Actual Production to Date..... 61,500 " " 8,807— 96.8% of Standard

Direct Labor Allowance on Actual Production.... $7,398
Direct Labor Actually Spent.................... 7,944—107.4% of Standard

Overhead Allowance on Actual Production....... $14,796
Overhead Allowance Actually Spent............. 16,156—109.2% of Standard

FIG. 23. Weekly Manufacturing Budget Comparisons

Plant and Equipment Budget

PURPOSE OF PLANT AND EQUIPMENT BUDGET.—The purpose of this budget is to give management accurate data to aid in planning and controlling expenditures for plant and equipment. The latter constitute the **producing capacity** of a company. The term "plant" is often broadly used to refer to buildings and all more or less stationary equipment, while the term "equipment" includes items of movable or

portable physical property used in production. From an accounting standpoint these items include all physical production asset costs incurred to purchase manufacturing facilities possessing a life longer than one year.

Although this budget is prepared under a variety of titles by different manufacturing concerns, the classes of expenditures it includes are quite uniform. Sinclair (Budgeting) classifies expenditures which should be covered by the plant and equipment budget as follows:

1. **Maintenance and Repairs.** Under this title are included those expenditures which are necessary to maintain the existing buildings, machinery, and appliances in normal operating condition.
2. **Additions.** From time to time expenditures must be made for new equipment which is neither in the nature of a renewal nor replacement but represents an addition to the total plant and equipment in use. This situation arises more particularly during periods of expansion when more buildings and machinery are needed to satisfy the demands of an increased volume of business.
3. **Renewals.** Notwithstanding maintenance and repairs, certain items of equipment must be renewed. New equipment of the same kind as that which has been discarded is called a renewal.
4. **Replacements.** Improvements and developments are continually rendering items of equipment inefficient in comparison with units of more modern design. Good management demands that the inefficient equipment be retired and replaced by the modernized machines and appliances.
5. **Prolongation of Life.** A situation frequently arises where machines, partially inefficient or obsolete, by partial rebuilding can be made into satisfactory units of equipment. Expenditures for this purpose, that is, for bringing machinery and appliances up to date and thus retarding obsolescence, are frequently called betterments. In reality the expenditures are made to prolong the useful life of the units.

PREPARATION OF PLANT AND EQUIPMENT BUDGET. —Because of the diversified nature of items in this budget, several individuals cooperate in its construction. These include the plant engineer, treasurer, general manager, and chief cost accountant. Inasmuch as items in this budget are concerned with machinery and plant, its preparation necessitates a study of adequate records of past expenditures of all classes supplemented by technical advice from the plant engineering staff. Primary contributions of the plant engineer in planning and enforcing this budget are:

1. Constant study of improved methods of factory construction, new machines, tools, factory layouts, and presentation of proposals for improvements to reduce costs and increase savings.
2. Preparation of periodical plant and equipment programs and presentation of such programs to production executives to show costs and how probable savings may be realized.
3. Development and preparation of a periodical maintenance program for presentation to operating executives.
4. Direction of a tactful educational program to obtain proper use and care of machines and equipment and cooperation with operators so that cost reducing improvements will become fully effective.

By performing the above functions, the **plant engineering staff,** with the aid of the cost accounting department in utilizing past records, makes a major contribution in developing the plant and equipment budget. In some cases such a budget requires revision if changes in the sales

forecast or production plans warrant it in the opinion of the budget committee. In addition to items of expenditure involved in replacing or adding to present plant equipment, the budget may also include repairs and depreciation, thus grouping all factors pertaining to the plant and its equipment.

In preparing the plant and equipment budget, the following questions must be kept in mind:

1. What is the estimated expenditure necessary for planned changes or additions to the plant during the budget period?
2. What capital is available for the planned expenditures?
3. What is the estimated amount to be charged to maintenance and depreciation for the budget period?
4. How urgent is the need for plant expansion or equipment replacement?
5. What is the comparative cost for construction or equipment now and at a future date?
6. What return can be realized on the investment, if expenditures are made?

CONTROL OF PLANT AND EQUIPMENT BUDGET.—The plant and equipment budget differs somewhat from the detailed operating budgets of a manufacturing concern. The operating budgets are primarily estimates of income and expenses of a department for a predetermined budget period. The plant and equipment budget is mainly concerned with the maintenance of machines, tools, and equipment and additions or replacements to the plant. Consequently, the plant and equipment budget involves expenditures which affect production operations through the budget period and perhaps for a considerable time in the future. This necessitates a somewhat different method of control of expenditures than those for operating budgets which may be broken down into weekly or monthly periods for purposes of comparison and corrective action.

Items of **maintenance and repairs** may be estimated fairly accurately on the basis of past experience records and the condition of present equipment. Forecasts of such expenses may be prepared on a monthly basis, especially if the business has a policy of preventive as well as corrective maintenance. Such forecasts, however, are always subject to change by unexpected breakdowns or other emergencies. Expenditures for **plant additions** or **replacements** usually involve sizable appropriations and are subject to approval and authorization of top management.

The most effective control of plant and equipment expenditures exists when the budget is properly planned on a long-range basis so that expansion and replacements can be made when the market is most opportune. If such a practice is not used, expenditures may be made unwisely during periods of relatively high costs which results in a large burden of overhead charges and affects the return on the investment.

SPECIMEN PLANT AND EQUIPMENT BUDGET.—Fig. 24 shows a simple form of plant and equipment budget. McKinsey describes this form as follows (Budgetary Control):

In filling in columns (4) and (8) the plant engineer will consult the works engineering department with reference to cost of repairs. The works maintenance department will supply information with reference to the amount of repairs to be made. If the company produces its equipment,

the works engineering department will supply data needed for column (5). If the new equipment is to be purchased from outside vendors, the purchasing agent will supply these data.

Column (6) on the plant and equipment budget states when the new equipment is desired. With this as a basis, the purchasing agent will state the terms on which the goods will be purchased and show date of payment.

PLANT AND EQUIPMENT BUDGET										
GROUP	OLD EQUIPMENT			NEW EQUIPMENT				Total Deprecia tion	Total Repairs	Value of Total Equipment at End of Period
	Amount at Beginning of Period	Estimated Deprecia tion	Estimated Repairs	New Equipment Required	When Needed	Estimated Deprecia tion	Estimated Repairs			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)

FIG. 24. Plant and Equipment Budget

This information is necessary for the preparation of the financial budget. If the equipment is to be produced by the company, an estimate must be made of the disbursements necessary for its production. Date given in column (6) is the date when the complete equipment is desired. It may require a considerable period of time for its production. During the process of its construction expenditures for labor and possibly for materials will need to be made. Under such circumstances, the estimated expenditures preceding the completion of the equipment must be determined and allocated to the proper period for the purpose of the financial budget.

SECTION 25

PLANT PERSONNEL

CONTENTS

Planning for Safety

Safety Organization and Training

Maintaining Interest in Safety

Engineering Factors in Safety

Safety Inspections

Purchasing Safe Equipment

Study and Analysis of Accidents

Maintaining Accident Records and Reports

Industrial Relations

Factors in Good Personnel Relations

SECTION 25

PLANT PERSONNEL

PERSONNEL ADMINISTRATION.—Because of its wide coverage and the many progressive developments occurring during the past few years, personnel administration is no longer confined within the limits of the dictionary definition or the definitions of some of the earlier writers on personnel. Thomas G. Spates, Vice President, General Foods Corp., widely known in the personnel field, offers this newer definition and the accompanying discussion (An Objective Scrutiny on Personnel Administration, American Management Association, Personnel Ser. 75):

> Sound personnel administration means so organizing and treating people at work that they will utilize their maximum individual capacities, thereby attaining maximum personal and group satisfaction and rendering their maximum service to the enterprise of which they are a part.

More broadly and definitely, he formulates his conception of this function of industrial operation thus:

> Personnel administration is a code of the ways of organizing and treating individuals at work so that they will get the greatest possible realization of their intrinsic abilities, thus attaining maximum efficiency for themselves and their group, and thereby giving to the enterprise of which they are a part its determining competitive advantage and its optimum results.

As early as 1923, E. K. Hall, of the American Tel. & Tel. Co., the first man to be given the title of vice-president in charge of personnel relations, and a pioneer in this field, stressed the **definitely individual nature of all contacts and relations** throughout an entire plant or organization. He said in his address on "A Plea for the Man in the Ranks":

> Now here is the plea I want to make for the man in the ranks. Make him a member of the team, just a straight honest-to-God member, and treat him like one until he realizes himself that he is a member. That will take time. It will take quite a lot of time. He does not think he is on the team now. He does not think that you think he is on the team now. He thinks that you consider your team consists of the men whose names are listed on your organization chart—the chart showing your line and staff organization. He thinks that he is working *for* that team and not *on* it.

Clinton Golden and Harold Ruttenberg (The Dynamics of Industrial Democracy), labor leaders who at the time of writing had negotiated contracts with 828 firms involving 660,000 members, voiced a similar conclusion:

> One of the compelling motives for union membership is the desire for workers to give their personalities dignity and their lives a meaning. . . .

The dynamic quality, the militancy, and the crusading spirit of the labor movement, especially of the C.I.O. in the last decade, were nurtured by the failure of management to satisfy the noneconomic needs of the workers.

Dealing with Workers a Duty of Line Authority.—The conclusion of leaders in personnel work, on the basis of firsthand experiences under modern plant operation, is that dealing with employees is a daily duty of line authority and the vital point of contact is where supervisors, foremen, group leaders, and others come into direct association with workers on their jobs. It is here that training, employee service, industrial relations, collective bargaining, morale development, and other functions and factors either pool their results into understanding, cooperation, teamwork and goodwill, or into grievances, hostility, limits on quantity of production, sitdowns, strikes, and outbreaks of violence.

INDUSTRIAL RELATIONS POLICIES.—So important is the relationship between the supervising and working forces that companies have found it highly advisable to state their labor policies specifically, provide definitely for carrying them out, and carefully to instruct foremen and others in the full, unvarying, and conscious observance and application of these policies. The Western Electric Co., for example, has issued a folder from which the following is quoted:

To Employees Responsible for Directing the Work of Others

It is the purpose of this statement to promote a more complete understanding of the company's Employee Relations Policy. Attention is called to your responsibility for carrying out all of its provisions and to the methods adopted for maintaining uniformity of practice in all departments of the company.

Although Personnel Departments have been established to advise and assist executives and supervisors in their dealings with employees, responsibility for making the policy effective in the everyday relationships with all employees must rest with you.

Right relations with employees is one of the fundamental elements in the success of the company, and must be founded upon the conviction of every employee that the policies of the company are based upon a spirit of justice in its dealings with every person with whom it comes in contact.

It is the policy—

1. To pay all employees adequately for services rendered.
2. To maintain reasonable hours of work and safe working conditions.
3. To provide continuous employment consistent with business conditions.
4. To place employees in the kind of work best suited to their abilities.
5. To help each individual to progress in the company's service.
6. To aid employees in times of need.
7. To encourage thrift.
8. To cooperate in social, athletic, and other recreation activities.
9. To accord to each employee the right to discuss freely with executives any matter concerning his or her welfare or the company's interest.
10. To carry on the daily work in a spirit of friendliness.

PERSONNEL FACTORS IN PRODUCTION.—The field of industrial relations and personnel management covers a wide range of important activities. While all such work is of either direct or indirect concern to production, there are certain factors relating to personnel in which the production man has an immediate and responsible part and must take some positive action. He has something to do with securing

plant personnel, and considerable to do with orienting employees into their jobs, training them on the job, enabling them to secure the available benefits from employee services, maintaining sound relations with workers, seeing that they are fairly treated, equitably paid, and turn out the proper amount and quality of work, that they observe plant rules and safety precautions, and that their active interest and willing cooperation is enlisted in the improvement of methods and equipment and in lowering costs of production.

Relations of Production and Personnel Departments.—The production man, used to dealing with so many physical factors whose characteristics are known and which follow definite patterns of behavior under definitely known conditions, requires the advice and assistance of the specialist in personnel to enable him to understand how to deal more successfully with human nature. Likewise, there are many personnel services of a special character, quite necessary to successful factory operation, but which cannot be performed by the line organization directly in the course of manufacturing. These services can be best handled by the personnel department on a factory-wide basis so that they are both definitely rendered and equitably performed for all workers alike.

Under proper organization, both production and personnel departments understand fully the line authority of the one and the staff service of the other, and settle all border cases readily. The clarification of functions is further carried out nowadays in some factories by assigning to foremen, under their line authority, assistants specializing in training, safety, handling grievances, etc. These assistants report to the foreman and act under his instructions. They receive training, guidance, and aid in their functional duties, however, from the personnel department as a staff service.

Contribution of aid and information is not all one-sided, from personnel to production. The production department must furnish considerable important information to the personnel department for the proper performance of its work. Included in the list are data on the kind and number of workers required, on job descriptions and specifications, job evaluation, merit rating, working history of the employee, accidents, attendance and absenteeism, layoffs and discharges, transfers, wage rates, training requirements, employee services, and many factors connected with labor relations and collective bargaining.

Personnel Organization

SCOPE OF PERSONNEL ACTIVITIES.—The full scope of personnel activities may be better understood by considering the functions of a personnel department in a large company, and then the functional set-up of an industrial relations department in a subsidiary plant of this company, or in a small independent manufacturing concern.

According to Roy W. Kelly, the functions in a large company would come under the jurisdiction of the president, or a personnel committee or a vice-president in charge of personnel, who would:

1. Supervise the work of a personnel director.
2. Arrange staff meetings for discussion of personnel policies, interpretation of company rules and regulations, and provide channels

of communication between top management and the supervisory forces.
3. Appoint special committees of executives and department heads, or staff members to consider special personnel problems or formulate new policies and procedures.

The personnel director would assist the management in formulating, interpreting, and executing personnel policies, act as staff adviser to executives, department heads and plant managers, represent the company in certain public relations matters closely related to personnel administration, and be the active and responsible head of the personnel department. He would have assistants who would direct and carry on the following branches of work:

1. Employment and occupational adjustments.
2. Training.
3. Employees' service and benefit plans.
4. Medical and health service.
5. Safety, fire prevention, and sanitation.
6. Joint representation and working conditions (collective bargaining, union agreements, etc.).
7. Statistics, reports, records, and research.

As applied to a subsidiary plant of a large company, or a small independent manufacturing concern, the functional organization of activities would be as follows. The plant manager, or the president of a small company, would have general jurisdiction and would:

1. Supervise the work of an industrial relations manager.
2. Direct conferences of superintendents, supervisors, and foremen for the discussion of personnel policies, interpretation of new rules or regulations and providing a channel of communication between top management and the supervisory forces.
3. Appoint special committees of department or staff members to handle such matters as collective bargaining, job classification, wage adjustments, pensions, etc. The industrial relations manager would usually act as chairman or executive secretary of such committees.

Under the direction of the industrial relations manager, assistants would carry on the same functional activities as are listed for the large company, but applied specifically to the immediate problems faced under actual plant operation. The various groups of functions listed do not necessarily imply a separate division in each case, with someone in charge. In small plants numerous important functions may be handled directly by the industrial relations manager. An appropriate grouping of functions depends in large part upon the experience and training of staff members of the department.

The production men will be called upon to participate in personnel activities in two ways:

1. Attend staff meetings or conferences for discussion of policies, interpretation of rules and regulations, or devising plans for the communication of personnel information throughout the organization.
2. To work with, and under the guidance of, the personnel department as a staff unit, in matters concerning the immediate application of policies or use of standardized procedures in connection with employment, training, employees' service, medical and health service, safety and other protective measures, dealings with workers, and the providing of data needed for reports, records, or in certain research.

While it is advisable for the production man to have a knowledge of the functions and work of the personnel department as a whole, the discussion in this Section will center only on those factors or activities in which he will have a direct or associated part.

METHODS OF ORGANIZATION.—The organization of industrial relations in one works of a large company is shown in Fig. 1 and the organization of personnel service in this same works is illustrated in Fig. 2.

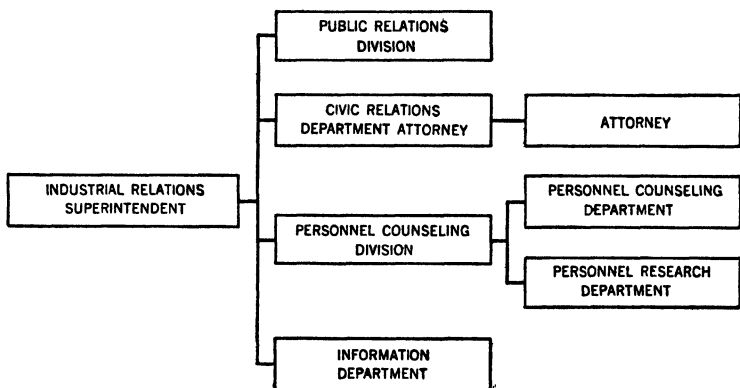



Fig. 1. Functional Organization for the Adequate Administration of Industrial Relations
(Western Electric Co., Inc.)

Another large company's organization chart of industrial relations activities is shown in Fig. 3. This work is headed by a vice-president who has full charge of the entire program. There are over 150 on the direct personnel department payroll and many more with functional authority who work with the department on various projects.

The following items, describing this latter organization, are quoted from Lee H. Hill, Vice-President, in charge of industrial relations in the Allis-Chalmers Co. (A.M.A. Pers. Ser. 63):

Industrial relations are coordinated by means of a Labor Policies Committee, composed of the general works manager, the vice-president and general attorney, and the vice-president in charge of industrial relations. This committee, which reports only to the president, is concerned with the formulation, interpretation, and evaluation of the over-all industrial relations policies. Matters upon which committee members are in complete agreement can be resolved without further ado; where there is disagreement, the matter is referred to the president. This arrangement permits quick decision and prompt action.

Another source of integration is provided by liaison agents who were appointed primarily to strengthen industrial relations functional control within various departments of the company and to expedite industrial relations matters.

The general manufacturing department released one of its best men to use for this purpose. He retains his old title of planning supervisor, with all

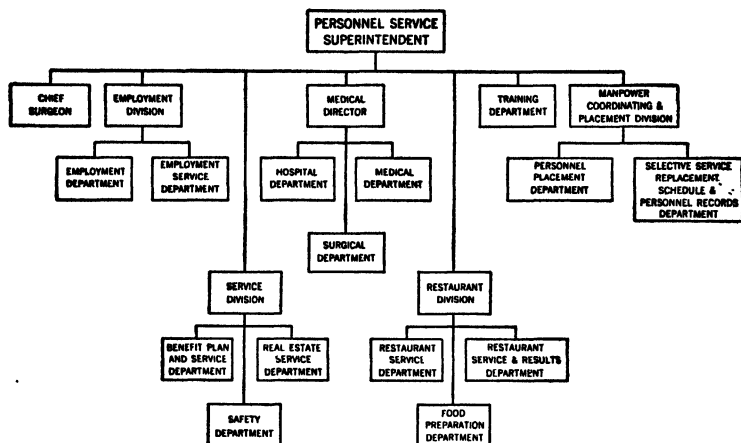



FIG. 2. Organization Plan for the Management of the Responsibilities of Personnel Service
(Western Electric Co., Inc.)

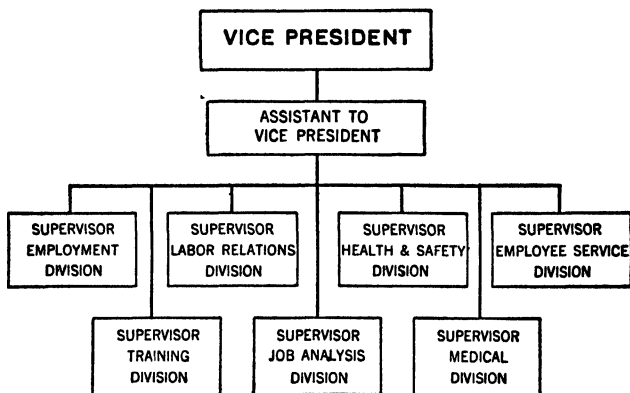



FIG. 3. Plan of Industrial Relations Organization in a Representative Large Manufacturing Plant
(Allis-Chalmers Manufacturing Co.)

the prestige that it carries, and reports directly to the general works manager, but devotes most of his time to expediting shop acceptance of industrial relations policies. . . . Another shop man, the advisory superintendent of the general machinery division, acts as the "yeast" in our training program. He assists in laying out the courses, then sponsors them and insures their acceptance by foremen and workers alike.

Similar arrangements have been made with other departments. The legal department has detailed one of its lawyers to our work. Then there are two men from the advertising department—one to coordinate industrial relations with the efforts of that department and the other to tie in its departmental objectives with our publications. With the accounting department members we have a negative as well as positive arrangement: We have supplied them with a list of our recurring expenses, and they question us on any additional items in order to insure a proper distribution of costs. They have also detailed a man to work closely with us in the preparation of data and in handling employee complaints affecting payroll matters. . . .

Each week we have a different supervisor from the manufacturing department as observer and adviser in our employment office; in fact, all our divisions must and do work closely with the various departments of the company, placing their members as heads of activities and as members of committees. . . .

Because discipline cases tended to reappear as grievances, causing considerable wear and tear on the foremen, it was thought advisable to centralize them; accordingly, the Discipline Control Board and the Industrial Relations Review Board were created. [The latter is a court of appeal for grievances.]

The industrial relations department is organized internally to provide maximum flexibility. Staff assistants and areas of responsibility are utilized to achieve this end. We believe in coordinating any two or more common problems that occur or recur within the organization.

As mentioned before, there is a Labor Policies Committee, which sets the over-all company policies. Reporting directly to the vice-president are eight supervisors, all heads of divisions. These, together with the vice-president, the assistant to the vice-president, and the departmental administrative assistant, constitute the Industrial Relations Staff Council. This group meets each week and more frequently when necessary. Problems brought up are referred to committees of three, usually composed of the supervisors whose functions are concerned. These men consult one another, work together, and report at the next meeting. Once a month, the council meets in lighter vein for dinner at the University Club and an industrial relations "bull session" afterward. This sort of meeting not only develops a friendly feeling but brings out problems that otherwise might go unnoticed. . . .

The employment division performs the customary work of interviewing, testing, and placing. It provides a particularly good orientation program, including two-month and six-month follow-up of new employees.

The exit interview technique is formalized and well developed. About three out of every 10 quits are salvaged for the company.

The health and safety division is especially active. It has developed a complete and accurate system of records which are useful in locating accident hazards and in directing prevention efforts. It designed work clothing for the new women workers and developed what is believed to be the first safety handbook for women.

The job analysis division performs the job rating and wage classification, prepares the wage rate manual and checks upon all requests for wage-rate change.

The labor relations division manages the mechanics of grievances, referee hearings, discipline cases, and correspondence with the union on collective bargaining matters. It also puts company policies in written form, maintains the policy manuals, and interprets them for supervisors.

The medical division runs the company hospitals, provides for employment examinations, and checks up on absenteeism. It does a noteworthy job of arranging transfers where they are necessary for the health of the worker, and of occupational placements of handicapped persons.

The research division analyzes personnel operations and evaluates results, acting as an internal auditor and controller, as well as carrying on research into new methods. In analyzing a policy or a procedure it uses the following questions:

1. How effective is it in terms of the objective for which it was designed?
2. What are the deficiencies?
3. What are the objectionable features?
4. What modifications could be made which would effect an improvement?

Our training division is conducting a multiple-activity program, for its work extends to all levels. Intradepartmental training is provided on both a group and an individual basis. The industrial relations departmental training is assisted by the research division, whose job it is to keep abreast or ahead of the latest developments in the field.

Each division operates on a working-time budget so that the costs of all projects undertaken can be readily determined.

Employment

DEFINITION AND FUNCTIONS.—The following definition states the responsibilities covered by the employment unit of the personnel department:

> Employment is that division of personnel activities which is concerned with recruiting, selection, hiring, and placement of workers.

In some organizations, transfers, promotion, and discharge are added to the duties of the employment department. Some companies also center industrial relations activities in the employment department, the head of which then functions substantially as industrial relations manager.

In the modern industrial establishment the employment department may have jurisdiction over any or all of the following functions:

1. Study of labor sources.
2. Job analysis and job specifications.
3. Interviewing applicants for work.
4. Physical and mental tests.
5. Selecting employees.
6. Introducing new employees to the job.
7. Placement, promotion, and transfer.
8. Layoffs.
9. Attendance and absenteeism.
10. Labor turnover records.

PLANNING PERSONNEL REQUIREMENTS.—The personnel department procures new employees only in response to the stated needs of executives, supervisors, or department heads, frequently expressed in written requisitions. It is advisable for factory and production control departments to investigate and forecast their needs for workers well in advance, to give the personnel department time to clear through and submit for approval and employment the proper kind and number of promising applicants to fill forthcoming requirements. In mass-production industries manufacturing standardized lines of products, where large

numbers of workers with the same skills or for the same kinds of jobs are employed, a labor budget is often prepared, estimates of the number wanted may be based upon the forthcoming production program, and employment activities may be planned to bring in the added forces as the schedule of output is increased. Such companies, moreover, can transfer workers between departments according to departmental work loads, although inefficiencies in personnel departments have been so great in some cases that new employees were being hired outside for certain departments while present workers with the same qualifications were being actually laid off from other departments in the same plant.

In smaller plants, especially of the job-shop kind, the needs cannot be so readily forecast in advance because of the variations in kind and quantity of output. Workers are not often hired until the need for them is pressing, and they are frequently engaged one by one instead of in larger numbers. Nevertheless, the production departments should pay at least as much attention to preplanning for personnel needs as for materials needs and equipment schedules. Regularized employment through job security, moreover, is one of the aims of the labor movement. It can be considerably advanced by economic studies and labor-need forecasts which, in many cases, may result in revisions of manufacturing schedules to cut down wide fluctuations in production, with their consequent layoffs, discharges, and rehiring. It is likely that the average cost of hiring a worker is above $200, and a technician more than $500—a cost often not regained until after several weeks' or sometimes a few months' service. Plants with substantial fluctuations in the number in the working force and high labor turnover, moreover, are usually highly inefficient in production and do not bear reputations in their communities as desirable places in which to work.

Preventing Needless Fluctuations in Employment.—There are many ways in which the production departments can prevent wide fluctuations in employment (Kelly):

1. Give advance notice of personnel needs.
2. Inform the personnel department of any proposed changes which will affect personnel, especially in regard to layoffs.
3. Assist in arranging transfers of workers to other departments to prevent layoffs and level off work loads.
4. Train workers on several jobs so that they may be more readily assigned to other work.
5. Hold special jobs in reserve for slack seasons.
6. Reduce working hours, but not to the point of reducing workers' incomes below a fair living standard.
7. Spread overtime among workers as equitably as reduced time or layoffs.
8. Build up a "flying squadron" of unassigned workers who have sufficient experience to substitute for absentees or in cases of overloads. They are regular employees and are entitled to the full benefits accorded all workers.
9. If possible, have a record of persons who may be available for temporary connections in seasonal work, overload periods, vacation time, part-time work, etc., or may hope later for permanent jobs. It is difficult to hold such persons unless they can be given 3 or 4 days' work per week, even in slack times.
10. Use dull periods to shut down the plant for vacations and do maintenance work which cannot be conveniently performed during production.

11. Standardize products as far as possible to cut down fluctuations resulting from variations in the manufacture of a wide range of products. This step requires the cooperation of the sales and engineering departments.

THE EMPLOYMENT CYCLE.—On the basis of two decades of experience, the employment procedures, forms used, and records set up and maintained in connection with applicants and employees have become generally standardized in content throughout industry, but not in arrangement and detail. Each company makes variations to suit its own immediate purposes. The following tabulation covers the employment cycle for a well-organized company with a good personnel department:

1. Requisitions for new employees are received from department head, supervisor, or foreman.
2. Job specification and job evaluation cards, if in existence, are supplied or consulted to find out the nature and pay of the jobs and the particular requirements for the workers.
3. Prospective applicants are secured through existing application file, contact with agencies, advertising the position, or personal contacts.
4. Application forms are filled out by applicants unless they have already done so.
5. Interviewer in personnel department inspects applications, and personally interviews the applicants who appear to be suitable.
6. Aptitude or intelligence tests may be given to those who appear to be good prospects.
7. At this point, unsuitable applicants are weeded out, given an explanation, and, if it may be possible to hire them at some future time, are encouraged to keep in touch with the company. Records of the reasons for their rejection are made and placed in the application file. Other applicants may be rejected at steps 8, 9, or 10. The likely prospects are then given another interview at which time they are told more about the company, their prospective jobs, and other factors.
8. Acceptable candidates are taken to the department head, supervisor, or foreman for whom they may work for a check on their detailed qualifications and to eliminate any between whom and the supervisor there may appear to be an initial feeling of personal dislike or lack of harmony.
9. References given by applicants are written to, or called up, to secure information on applicants' characters and backgrounds and perhaps experience records.
10. Applicants remaining after the successive weedings out are sent to the medical department for physical examination. There is probably a growing tendency to conduct psychological or psychiatric interviews also at this point to eliminate definitely undesirable candidates or recommend procedures for dealing on a more scientific and personal basis with accepted employees who may display certain erratic characteristics.
11. Identification records are made when the applicants report for work.
12. Applicants are inducted into their jobs. The simplest procedure is merely to conduct them to supervisors who put them to work at once, preferably under guidance until they are properly broken in. The best procedure, however, is to give them a preliminary preparation through a meeting, or preferably a brief training period, in which the business of the company, its organization, objectives, policies, layout, methods of operations, safety provisions, training courses, employee services and benefits, methods of dealing with employees, wage plans, and general rules and regulations are fully explained. The employment or the training department usually conducts the

latter kind of induction, after which the employee is taken to his department and introduced to his supervisor.

13. Employee records are set up in the personnel department in which all data and forms, beginning with the application letter or blank and including all the information collected throughout the employment procedure, are filed for reference purposes.
14. An employees' history file is begun in which is collected for each person on the payroll a complete record of his activities and relations during his employment. This record should be reviewed periodically for the good of both employee and company. It includes:
    - a. Attendance and punctuality reports.
    - b. Summary of earnings, including wage or salary rates.
    - c. Merit rating reports.
    - d. Training reports.
    - e. Accident and lost-time reports.
    - f. Warning reports on his violations of important company regulations, any serious or repeated failures to meet task standards, carelessness regarding safety, etc.
    - g. Promotion and transfer records.
    - h. Layoff and demotion records.
    - i. Termination notices, with record of exit interview.
15. The new employees' names are recorded in the cross-reference index for the files kept in the personnel department.

For the reemployment of returning veterans many companies have set up separate units because of the wide scope and important nature of such responsibilities. These units include sections for interviewing, counseling, medical service, and training.

JOB SPECIFICATIONS.—Increasing use is being made of job analysis, job descriptions, and job specifications as aids in fitting workers to particular tasks. **Job analysis** is the term applied to process of breaking down a task into its different operations, studying operations separately, determining special training, skill, strength, and other qualifications necessary for each, and the time which each should consume. This form of analysis is used not only in connection with employment, but often as an aid in classifying positions as to wage rates, and for setting piece rates and other incentive wages. In this Section it is considered only in connection with employment.

Job descriptions are brief, to the point, and often preliminary write-ups of jobs to state the nature of the work and duties in a clear, definite, and concise manner, and the qualifications of the workers to be assigned to such jobs. They are the intermediate stage between job analysis and job specifications and are convenient for general or temporary use.

Job specifications are more comprehensive, specific, and detailed than the descriptions. They consist of full descriptions of accurately defined jobs, with information as to wage rates of each, working conditions, and prospects of promotion, qualifications required of workers, and kind of worker who can best fill the place. In most approved practice, sheets giving specifications for each job are furnished to the employment manager and to foremen or superintendents of departments affected. A foreman, in placing requisitions for workers, merely specifies the jobs which are to be filled, and the employment manager, by consulting his specification sheets, can ascertain what kinds of persons to hire for these jobs.

Job specifications are useful in the employing function because they make it easier to select the workers needed for the various places to be filled, thus reducing the proportion of misfits and decreasing the danger

of all-round misunderstandings. They assist, for example, by calling attention to safety precautions necessary on certain jobs and thus warn the employment interviewer to be specially alert against accident-prone applicants. However, they are no substitute for the employment man's personal familiarity with working conditions. Employment managers and interviewers should spend a certain amount of time in the factory with department heads, supervisors, and foremen to assure familiarity with the duties, responsibilities, and conditions surrounding each position.

Specifications for each task should include at least the following facts:

1. Name of job, with key number or letter by which it is designated.
2. Kind of work.
3. Working conditions, especially in respect to temperatures, dust or fumes, unpleasant processes, odors, etc., and exposure to injury or occupational disease; safety provisions which must be observed.
4. Nature of operation; whether work is light or heavy, varied or repetitive.
5. Kind of skill required, if any.
6. General procedure followed in doing the work.
7. Previous experience desired.
8. Type of worker most desirable for task; American or foreign, white or colored; physical qualifications; age; temperament; intelligence; education; any other special qualifications.
9. Starting rate of pay.
10. Prospects for promotion to other jobs, or for increases of wage rate.

Specifications should not be too rigid or exacting. Opportunity should be left for the employment of "second choice" workmen if those who completely fill the specifications are not to be found.

EMPLOYMENT TESTS.—Various forms of tests have been successfully used by a growing number of leading companies, with definite success. They are applied to supplement interviews, physical examinations, investigation of past records, and other methods of determining an applicant's competence. The tests can be used as a condition of employment, whereas it is harder to apply them later if they are opposed by the workers.

Tests may measure certain essential characteristics which cannot be accurately determined otherwise. Successful testing must be carefully integrated with well-rounded employment procedure, job analysis, training, adequate supervision, and evaluation and development of opportunities for growth and promotion in the organization.

Employment tests may be grouped as follows:

1. Tests of general intelligence.
2. Tests of personality traits or of emotional stability.
3. Trade or job tests, designed to indicate skill, ability, or technical or trade information in a single occupation or limited field.
4. Tests of interests, of special aptitudes, or of basic ability to assimilate training or acquire skill.

Achievement in any test is significant only when it bears some direct relationship to occupational success. Accordingly, tests must be standardized, and their administration and the norms established must be with reference to minimum abilities essential to satisfactory job performance.

Reliability and norms for any test may be established from a large number of cases by either: (1) using it with persons whose performance

is subject to measurement and whose relative success or failure is known, or (2) using it on applicants whose achievement is later determined.

Various important results are secured by the use of tests whose reliability and validity have been appropriately determined. For example:

1. The percentage of applicants who prove to be satisfactory is improved.
2. Output is increased by employing more competent persons.
3. Employees are selected for promotion or special training with greater assurance of success.
4. Assistance is secured in handling problem cases.
5. Evaluation of job conditions for tests is helpful in considering other matters, such as wages, working conditions, training, etc.
6. Employees below standard can be selected for special training, transfer, or other suitable action.
7. "Pressure" cases, where the applicant has been recommended by relatives, customers, or politicians, can be handled on a fairer basis.
8. Guidance and advice is given to employees on a more concrete and objective basis.

For many purposes, a group of tests, usually known as a "battery," may be more effective than any single test. In special cases, several tests may be modified or merged into a single testing procedure. Testing ought never to be undertaken, however, without experienced professional supervision, either in employment or in training.

Experience with Tests.—As indicated, the reliability of tests may be checked by later evaluating the work of those who took them. The Martin & Schwartz Co., Inc., subsidiary of Sun Oil Co., was called upon to transfer its workers to large-scale manufacturing of new kinds of equipment on which the work consisted almost wholly of machining operations. After making preliminary tests of 40 employees of known ability, the company applied the tests to all its employees and new applicants. The tests used were: revised Beta (nonverbal) intelligence, Bennett Mechanical Comprehension test, two-hand coordination test, hand-eye coordination test, and hand-tool dexterity test. After about a year, employee ratings were made of transferred employees and new workers by shop supervisors well acquainted with their job proficiencies. A comparison of ratings with the test scores of these shop workers showed the following conditions:

1. Ninety-one per cent of the workers rated "excellent" had scored A or B on tests.
2. Seventy-five per cent of the workers rated "good" had scored A or B on tests.
3. As ratings went from "excellent" to "poor" the proportion of those who had scored A on tests decreased progressively, while the proportion with D scores increased correspondingly.

New employees had been hired only if they scored A or B on tests, and were found to be rated appreciably higher in general than older employees. Seventy-six per cent of the new workers were rated by their supervisors as "excellent" or "good," only 8% "below average," and none "poor." No new employee had to be discharged for lack of ability. The study also revealed many men, scoring high in tests, who were qualified for higher-grade jobs and were transferred to them. Checks showed that the Bennett Mechanical Comprehension tests and the hand-tool dexterity test produced the highest correlation with the supervisors' ratings, and

these two tests could be taken by an applicant in about 35 minutes (George K. Bennett and Richard A. Fear, Personnel Journal).

AUTHORITY FOR SELECTION.—Final authority for the selection of the applicant should not rest with the employment department, but rather with the department head, supervisor, or foreman for whom the employee is to work. In some cases psychological factors are involved, such as the occasional immediate hostility of the foreman and applicant who feel that they just could not get along with one another. However, supervisors should not disregard the advice of the employment department for trivial reasons or personal prejudice.

During the interview, it is the duty of the prospective employing foreman to make a brief but pointed check on certain details of experience and aptitude, and possibly on the general caliber, attitude, and capabilities of the applicant, for the foreman will have to utilize the abilities of the new worker after he is employed and should have both the opportunity and responsibility of deciding whether he will fill the requirements as they exist on the specific job.

INTRODUCING THE WORKER TO HIS JOB.—Under such a plan the worker will already have met his supervisor when he goes on the job. There are other factors, however, besides the job itself which the new employee must know if he is to harmonize and team up with the remainder of the organization. For this purpose it is best, especially in a medium- or large-size company, to have some plan for orientation of workers when they take their jobs. Sometimes the employment department carries on this work and sometimes the counselors do so, but the training department may take over this duty as the closing act in a preliminary training program by concentrating at least a major portion of the orientation program in a regular session for new employees before they report to their respective workplaces. Some specific departmental rules may be stated and other explanatory remarks may then be given the employee by the supervisor when he reaches his new place of work, but the general background will already be provided.

A sound orientation program for new employees consists of both lectures and demonstrations and should cover:

1. Welcome by company official.
2. History of the company.
3. Company personalities.
4. Company plant and shop organization.
5. Timekeeping and payroll procedure.
6. Union affiliation.
7. Employee services, such as medical, counseling, cooperative store, etc.
8. Safety and health rules.
9. Plant protection regulations.
10. General rules.
11. Summary and expression of goodwill and interest in the employees' progress.

An excellent conclusion for the program is the presentation of the employees' handbook, if one exists, plus any general literature which is available on the company or its products. If the company publishes a house organ, each new employee should be given a copy of the latest issue. If the company has a moving picture of its products and their processing, it should also be shown as part of the program. The inspira-

tional value of all such items is particularly high at the time the employee begins work and is enthusiastic about everything connected with his new job.

Induction may be defined as the process of introducing the new employee to his new supervisor, job, and workplace. Its value under the plan just outlined is important, since all the good of a careful orientation program may be negatived by the gruff attitude of some foreman, if the new employee is merely sent to his department. If a guide from the training department takes him to his new workplace and introduces him to his supervisor, this unfortunate outcome is not likely to occur. A follow-up of this program after a week or two serves to correct any false impressions gained in the early days of employment, or to answer additional questions that may not have been answered by anyone in the department.

PROMOTIONS.—It is desirable to try to fill supervisory and other advanced positions by promotion from within the organization. Otherwise, capable and ambitious persons will soon leave. In the absence of a well-thought-out plan of promotion, the most promising workers often reach a ceiling in their departments and find no way of getting further. Sound procedure calls for the analysis of all jobs to establish definite lines of promotion based on the attainment by the employee of certain standards of accomplishment. It is impossible to guarantee that there will always be immediate opportunity to advance employees to higher jobs, but the eventual possibility should be definitely planned, and can ultimately be brought about if job specifications are developed, job evaluation and merit rating are applied, and the channels of advancement are properly plotted. Lack of such plans explains the ultimate stagnation of some companies and finally necessitates their complete reorganization.

Periodical check-ups to see how new employees are getting along are of decided advantage. Such checks show whether the employee is taking the necessary steps to qualify for promotion. Special training can be urged, and perhaps offered, by the company where additional skill or technical knowledge is required for advancement.

Most employers prefer not to follow the rule of strict seniority in promotion and do so, if at all, only under compulsion of union contracts. Union contracts should contain some form of "merit clause" which requires consideration of the worker's qualifications as well as length of service before promotion or transfer is approved. At the same time, however, length of service is given appropriate weight in deciding between employees of approximately equal ability.

When actual promotion is not possible, an employee may sometimes be aided and encouraged by **transfer to a job of equal rank** with his own, but which for some reason is more agreeable to him personally. In the whole matter of transfer and promotion, supervisors and foremen should recognize the ambition of the intelligent workman to advance in his line of work. Lack of such recognition is responsible for much ill-will, discouragement, and inefficiency.

TRANSFERS.—Transfers of workers may be recommended for a variety of reasons: correction of faulty placement, trial on different work for employees unable to handle their first assignment, opportunity to develop versatility or to gain better general knowledge of plant opera-

tions, to provide temporary work during slack periods, to relieve monotony, because of the health or age of the worker, to place the worker in a location favored for personal reasons, as a disciplinary measure, or because of incompatibility among workers or between worker and supervisor.

An acceptable system for handling all such matters must be based on carefully developed policies, adequate individual records of employees, time and ability on the part of competent persons to investigate the individual cases, and a sincere attempt to compose divergent or antagonistic points of view.

RESERVE WORKERS.—Some companies have formed floating reserve forces, or so-called "flying squadrons," to avoid the necessity for having an ample supply of regular workers in each department at all times, which frequently may bring about a large number of temporary layoffs. The members of such reserve groups are trained to do different kinds of work in different departments, so that they can also substitute for absentees. The reserve force is drawn upon for any extra workers needed when production goes above normal volume in any of the departments, until, of course, the general demand throughout the entire company, or the quitting of a portion of the regular forces, causes the need for additional outside hiring.

LABOR POOL.—Lack of utilization of the abilities of workers is frequently a cause of waste of manpower in a plant. Each employee should be asked to fill out a questionnaire indicating the kinds of work he feels qualified to do, or be trained for, besides the task which he is already on. Interviews may then bring out details for the records. Transfers may often be made, to the employee's advantage, if it is found that he would like some different kind of work. During peak loads in some departments it may be advantageous to assign workers from other departments running light, to tide over the emergency without adding employees to the payroll. When layoffs are necessary, it is possible to retain the more versatile employees for use on a variety of jobs, as required, and let the less-qualified workers go.

The York Corporation, as a result of a three months' survey among its thousands of workers, discovered that every man was competent in at least one additional skilled occupation, some in four or five. A total of 30 factory skills was listed. Seventy per cent of the salaried workers, among them many in the executive groups, were found qualified for 20 different jobs. During peak emergency activity since the study was made, as high as 10% of the entire personnel have been transferred in one month. Some transfers were permanent (Printers' Ink, vol. 204).

LAYOFFS.—When a general reduction in force becomes necessary, all layoffs should be carefully planned. Seniority is usually the first consideration, although attention may also be given to dependents, possibility of placing employees with outside concerns, and the individual employee's general value to the company. Layoffs are usually planned by analyzing the forthcoming production program of each department, determining the nature of the work and the kind and approximate number of persons required for each type of work, and realigning the working force set-up accordingly. Workers in the lowest grades of occupations and having the least seniority are frequently laid off first. The

numbers in the top grades are reduced by successively transferring down to lesser levels the necessary number of those with the least seniority in each group, but keeping each department in balance according to the respective occupations and skills in demand. Workers may often be transferred to other departments if in this way a better labor balance is possible, their skills can be utilized, and their rates of pay more nearly maintained. Recall to work is usually made on a seniority basis among those thus temporarily laid off.

DEMOTIONS.—When reorganizations occur, or when reductions in force make some action necessary, employees may be asked to accept positions of lower status or pay. In these cases length of service is usually the primary consideration, although attention must also be given to retaining employees of exceptional ability even if they have less seniority.

Demotions may also be made because of inefficiency, incompetence, as a disciplinary measure, or because of a decline in physical and mental energy occasioned by excessive demands on the human system, or advancing age. When such cases occur, the decision must be made as to whether the employees' compensation will also be reduced. In the majority of cases, if the pay is not cut, complaints arise sooner or later because employees on the same job are drawing different rates of pay. It may be more acceptable to the employee in some cases to be pensioned rather than to accept a substantial reduction in status and pay. Arbitrary retirement at a fixed age is of highly questionable value if the individual is possessed of his faculties and retains interest, good health, and vigor, that is, if he wants to, and can still do, good work. No company can fix rules of such a kind which are fair in all cases.

Full consideration of all the facts is not likely to be given unless control or review of such actions is in disinterested hands. The **policy governing promotions, transfers, demotions,** and **layoffs** should be intelligently formulated, kept reasonably flexible, and given careful and discerning supervision.

TURNOVER OF LABOR.—Labor turnover is the ratio of separations, or of replacements, to the total number of employees. The simplest method for its calculation, accurate as far as it goes, is to divide the total number of separations for the period in question by the average number of employees on the payroll during the same period. Thus, if in a year 1,000 men quit, out of an average working force of 2,000, labor turnover is:

$$T \text{ (turnover)} = \frac{S \text{ (separations)}}{A \text{ (average working force)}}$$

$$T = \frac{1{,}000}{2{,}000}, \text{ or .5, or } 50\%$$

Many companies in computing labor turnover divide it into different groups, according to causes, such as layoff, quits, discharges, etc., with a fairly complete analysis of the reasons for voluntary leaving. Some companies make a distinction between **preventable and unpreventable turnover,** putting into the latter classification those separations which result from reductions in the working force, or from deaths of workers. Likewise, some companies record turnover separately for old and new em-

ployees, for men and women, for skilled and unskilled labor, and for other factors of difference.

If turnover is high because of voluntary separations, the causes should be found and corrected. Low pay, poor working conditions, insecure employment, bad reputation of the company in the community, domineering bosses, unfair treatment, inability to get promotion, retention on boresome or objectionable jobs, wage-rate or earnings disputes, better jobs in other companies, and getting on a day shift instead of a night shift, are only a few of the many causes of "quits." An exit interview of a friendly nature should be held with all employees severing company connections. Some desirable employees can be induced to remain by correcting causes of severance, or showing how they may be better off in the end by remaining. All causes that are faults of the company, or supervisors, or other controllable factors should be investigated and corrective measures taken to eliminate the trouble. Loss of morale is one of the major causes and may arise from a wide variety of conditions or occurrences. To neglect correction is to lay the groundwork for more serious labor troubles later on.

ABSENTEEISM.—Absenteeism occurs when a worker stays away from the plant at a time when he normally would be expected to be present. The absence may be voluntary or involuntary. Total absenteeism may be calculated as consisting of both causes but it should not include vacations, time lost because of accidents in the plant, and similar good company reasons. Absences from death or illness in the family, personal illness, and similar unfortunate causes are not the fault of the employee and should be classed as involuntary and without detriment to his record. Some absences are occasioned by unpleasant working conditions, disagreements with supervisors, dissatisfaction with the company, and other causes which lower morale. Frequent absences, unless from actual illness or home troubles, usually are a forerunner of "quits" and should be quickly investigated, especially in the case of valuable workers, who may need some kind of assistance.

Remedies within the control of the production department are much the same as those cutting down "quits." They include: increased safety precautions and better attention to keep working conditions correct to avoid illnesses, better health maintenance provisions, sick benefits and medical assistance, setting shifts and hours to assist the employee to meet demands upon him (such as shopping, in the case of women workers), careful follow-up of new workers to arouse and maintain their interest, education and training of workers to stimulate their liking for their work, job evaluation to adjust wage inequalities, merit rating to give recognition and suitable advancement to qualified workers, incentive pay for good attendance, radios for news, music, and other entertainment in sections of the plant where such means are feasible and not annoying, and all other measures which stimulate high morale in individuals and the entire working force. Such plans have had wide success.

Factory Management and Maintenance survey figures place average absenteeism at 5.7%, the U. S. Bureau of Labor Statistics typical data have set it at 5.4%, and the C.I.O. adjusted estimates have been 4.5% for men and 6.5% for women. When the percentage of women workers is high, absences tend to increase especially where a considerable portion

of the women workers have families for which they are responsible. Family demands, particularly where there are children, home duties which absorb otherwise leisure hours and lower the store of reserve energy, and illness of members of the household, add to the normal causes of absence.

WOMEN WORKERS.—There will probably be a permanently higher percentage of women workers in plants, because of the ability displayed by women to perform certain tasks more efficiently than men, and other tasks equally as well. Important considerations in the employment of women in factory jobs have been summarized as the result of a survey by Edward J. Kunze (Women in Industry, National Metal Trades Assn.) who makes the following comments:

Women are different from men; hence, if they are to be employed to best advantage, their characteristic differences should be examined and provided for so far as it is possible to do, before dissatisfaction and disgruntlement take root.

Women in general are not considered by some employers to be as stable emotionally as men. They are more sensitive to criticism, feel things more keenly, are more easily discouraged and more likely to become emotionally disturbed than men. They are more critical of each other than are men. As a rule, women are less personally ambitious regarding their jobs than men, due very likely to the fact that they do not look upon the jobs as permanent. Women are more patient, industrious, painstaking, and efficient about doing the same thing over and over again; accepting routine work more graciously than do men. They are more careful with details. Their patience prevents them from becoming irritable due to monotony, especially when refreshed by suitable rest periods.

Once their domestic problems are solved, women stand the routine, grime, and noise of factories as well as or even better than men. Factory noises bother some women when they are new to factory work, but soon they find them less nerve-racking than irritable babies. Women, however, are sensitive to dirt, unpleasant odors, and lack of good housekeeping. They are more fastidious about their personal appearance. They tire faster and are said to be more adversely affected by heat and toxic fumes than are men, although this is denied by some physicians. It may be that restrictions in their occupations are due to women's tendency to become genuinely sick because of some emotional objection to her occupation. It is generally assumed that women have little more than one-half the strength of men; perhaps this is due to a lack of necessity, heretofore, to do laborious work. Russian women do as heavy work as do men.

Women's physical structure, however, is radically different from that of men; their muscular development is unlike that of men, hence their staying powers at hard physical labor are limited relatively. While women are usually shorter in stature than men, proportionately their torsos are longer, hence their legs are shorter proportionately than those of men; and work benches, chairs, and shelves should be designed to fit the average woman's physique. Shorter arm length calls for shorter levers on machines. Women's Bureau Labor Bulletin No. 189–1 gives the average woman's physical strength as 57% that of man and her resistance 67.9% that of man.

Women have a competitive spirit which causes them to desire to make a showing when placed in a new situation, which takes the nature of a flair. This has caused them, in many instances, to exceed the efficiency of the men they displace. Their sensitiveness of touch and deep concern in their work cause them to break less small drills than are broken by men. In a like manner they are well fitted to do both hand and machine tapping. If we face these facts and use them intelligently, much trouble, which may be difficult to overcome, will be avoided.

HANDICAPPED PERSONS.—The effective employment of the handicapped is now more than an incidental consideration in industry. Dr. Lillian M. Gilbreth, from extended experience, emphasizes the necessity for giving it most careful attention. Requirements in employing such persons are care by supervisors and foremen as regards kinds of work, training, delivery of materials, removing of work, safety provisions, and so on. The psychological approach is very important. With intelligent study of job and worker, handicapped persons can become very efficient The Ford Motor Car Co.. Eastern Aircraft Co., Arma Corporation, Caterpillar Tractor Co., Bullard Company, RCA Victor Co., Brown-Brockmeyer Co., General Motors Corp., Goodyear Tire & Rubber Co., and Vultee Aircraft, Inc. are some of the many concerns in different lines of manufacturing who are following definite policies for successfully employing handicapped workers. Essentials common to their methods are finding the kind of work handicapped people can do and training them to do it. The variety of jobs which these workers are actually handling with unusual capacity is amazing. Many agencies, federal, state, and private, exist to reequip handicapped individuals for factory jobs, and numerous informational aids are available.

Employee Services

MEDICAL SERVICE.—About half the cases of absenteeism in industrial plants result from illness. Losses to the company because of employee illness are in considerable part the same as those for industrial accidents. The worker loses his time, suffers from lowered energy and vitality, and may even lose his job. Health and medical services are therefore important, and usually promote goodwill.

Scope of Activities.—The amount and character of medical service will depend in part upon the size of the plant. In general, the essentials may be listed as follows:

1. A plan for medical services and a qualified staff of physicians, nurses, etc.
2. Prehiring examinations.
3. Periodic reexaminations, especially for those handling food products, drugs, etc., and for older employees.
4. Correction of defects found upon examination.
5. First aid for accidents and illness, and diagnosis of illness.
6. An adequate emergency dispensary and hospital facilities.
7. Efficient care of industrial injuries and occupational diseases.
8. Elimination or control of all general health hazards.
9. Use of approved hospitals wherever available.
10. Advice and assistance in securing competent medical and dental care and appropriate hospital service.
11. Group plans covering payment for hospital and medical service.
12. Control of occupational health hazards.
13. Inspection of sanitary facilities, lunchrooms, drinking water, salt dispensers, and the like.
14. Cooperation with family physicians, local hospitals, clinics, and specialists.
15. Health education.
16. Special examinations when required, such as eyes, teeth, hearing, mental tests.

17. Adequate medical records.
18. Medical testimony in compensation or legal cases.

Use of Community Facilities.—Where less than 150 persons are employed, appointment of a nurse or part-time physician is not always justified. Reasonably good results can be secured by using local clinics, dispensaries, or hospitals, cooperating with other companies by utilizing joint facilities, and by employing a physician on a consulting basis. Nurses who have had some clerical training or experience can sometimes be employed to do clerical work and take care of first aid. Use of poorly trained persons lacking professional qualifications for first-aid work is dangerous.

MEDICAL EXAMINATIONS.—The principal objectives of the medical examination are to:

1. Aid in placing workers on jobs which they are physically and mentally able to fill.
2. Detect remediable physical defects.
3. Determine the presence of serious organic diseases, impairment of function, or disabilities such as hernias, which may later be aggravated by employment or made the basis of a compensation claim.
4. Prevent spread of communicable disease.
5. Increase the economic efficiency of the worker by encouraging him to seek the correction of conditions of which he may not have been aware, or which are being ignorantly or thoughtlessly neglected.

Workers profit by thorough medical examinations quite as much as does the employer. They are safeguarded against being placed on work for which they are physically unsuited, and fair treatment is assured when failure on the job is due to disability.

Applicants are usually divided into classes by the examining physician: those fit for any kind of work; those employable on condition of recovery from disability or having necessary repair work done; those suited for limited employment, not to be transferred to certain types of jobs; those unconditionally rejected.

Value of Preventive Measures.—The best way to cope with industrial injuries and illnesses is through prevention. Members of the industrial medical department should appreciate this fact and cooperate as far as possible with safety engineers, supervisors, and others charged with the responsibility for safety in the plant. Many unsafe practices and unsafe conditions can be discovered in the medical department while injured employees are being treated, and this information should be transmitted without loss of time to those responsible for corrective measures. Also, in the medical department there is opportunity for instructing employees in ways to avoid accidents and illnesses, and this work should be carried on to the fullest extent.

Other Medical Activities.—The medical unit is sometimes called upon to present lucid, precise answers to such questions as:

1. Do occupational disease or accident hazards actually exist in the shop or workroom?
2. Is the employee actually suffering from an industrial accident or an occupational disease as he claims?

3. In the case of an accident where and how did it occur? For some disease, was it contracted or aggravated while the person was employed, or otherwise?
4. Are the effects of the accident or disease such as to cause disability? If so, when or under what conditions can the employee return to work?

Other equally complex problems arise in connection with administration of group insurance where coverage includes compensation for time lost due to illness, or for total or partial disability.

HEALTH EDUCATION.—Any successful program of health education must start with the foremen and supervisors. The basic problems of health improvement and the economic significance of absenteeism because of illness should be frequently stressed. The primary responsibility of the foremen is to be alert for signs of lowered vitality, fatigue, or symptoms of incipient illness. If their cooperation is secured in sending employees promptly to the clinic for first aid or diagnosis, half the battle is won. Employees who frequently act "queer," are often out of sorts, or are guilty of conduct which disturbs and upsets others should be reported to the medical department. Detailed study of clinic records should be made to discover chronic cases, repeaters, or those guilty of malingering. Illness among women workers may be reduced by having a nurse in attendance at the women's rest rooms, special health talks by specialists or women physicians brought in for the purpose, and recommendation of difficult cases for consultation with the physician. Informal talks to all employees, posters, bulletins, exhibits, and visits to neighboring hospitals or clinics may contribute to the success of health program.

MENTAL PROBLEMS.—Mental cases make up a peculiar area where intensive work with individuals must be substituted for mass economic, sociological, or statistical methods. Most companies cannot afford the services of a full-time psychiatrist, but many problems in selection, placement, discipline, training, and morale affect apparently well-balanced individuals as well as those who are known to be unstable mentally or emotionally. The objects of giving special attention to such cases are to: (1) discover underlying and often unsuspected emotional and social factors causing disturbances, (2) readjust workers' attitudes toward management, other workers, their jobs and their general situation in life, (3) develop individuals suited for promotion or training to assume special responsibilities, (4) inspire the group to greater personal achievement, and (5) devise incentives, rewards, and extra compensation or benefits to secure the cooperation of those with mental upsets, in their own reconditioning.

ECONOMIC SECURITY.—One of the employee's chief concerns is economic security, which can arise only from: (1) good wages and wage stabilization, (2) opportunities for adding to earnings, such as by incentive or bonus plans, sharing in some equitable manner in the company's earnings, etc., (3) the reasonable assurance of continued employment, (4) financial provisions definitely made to protect against contingencies, and (5) specific financial provisions for building up a competence for retirement.

Equitable Wages.—A consistent, fair wage policy is generally conceded to be one of the basic essentials in any successful industrial relations program. The vast majority of grievances among employees, as well as a preponderance of labor disputes, arise either directly or indirectly over wages. Just and equitable handling of this problem requires the collection and analysis of a substantial body of basic information and the elimination of decisions based on personal bias or prejudice. Necessary elements include:

1. Adequate personnel records, covering each employee's qualifications, work history, earnings, production, accidents, illness, suggestions, and other pertinent facts.
2. Information regarding rates paid for similar work by other firms; general wage trends; basic economic factors affecting wages—all collected and analyzed at least every 6 months.
3. Accurate, detailed analysis of each occupation, indicating basic requirements of each position and qualifications necessary to fill it.
4. Some systematic method of classifying or evaluating jobs.
5. Periodic review of wages and salaries.
6. Clear-cut policy determining basis for wage and salary payments.

Among comprehensive plans which have been adopted by manufacturing companies to provide economic security for their employees is the program set up by the Lincoln Electric Co. In 1914 an advisory board was set up to develop the normally unused abilities inherent in the organization. This board was composed of elected representatives, one from each department, one from among the foremen, and the plant superintendent and the president, the latter serving as chairman. This board has authority over all matters affecting the men and shop operations. The same year the company decreased hours per week from the usual standard, 55, to 50, increased wage rates 10%, and installed guaranteed piece rates. The next year it insured the lives of all workers for the equivalent of a years' wages at no cost to the employees. Later it introduced a bonus plan which was not at the time successful. In 1923 it began to give all workers 2 weeks' vacation with pay, shutting down the plant. Two years later it offered workers opportunity to buy company stock, which more than half have now done, owning a substantial share in the company. A suggestion system was established in 1929, awards being half the first year's net estimated savings from accepted suggestions. In 1934 the present bonus system was installed, amounts paid being based on the success of the company and the distribution proportioned to the value of the man to the company for the year. The president, alone, does not share in the bonus, but fixes the apportionments. Two years afterward an annuity plan was set up to provide for workers' retirement. This plan was followed 5 years later by a trust plan.

These provisions have raised the standard of workers' pay to the highest levels of industrial wages, a step made possible because of the constant incentive to production, high efficiency, and low-unit-cost operation, brought about by the two factors which are most effective in getting work well done—high and equitably distributed wages, and fair treatment and good opportunities in the plant (J. F. Lincoln, Intelligent Selfishness and Manufacturing).

Elements in Security.—There are a number of special provisions whereby a company may assist constructively in building up economic security for its regular workers, often bringing about much greater pro-

tection and benefits than individual workers could secure for themselves. A factor in this result is the willingness of individuals to do things as members of a group that they would not consistently do by themselves. A second factor is the lower cost of protection and future-income guarantees when pooled for a large group than when arranged individually.

The plans usually offered for the greater economic security of employees can be merely listed here, detailed information being available from many sources in specific cases. Only limited reliance should be placed on federal provisions for socialized services, which can hardly be equitably administered, and actually bring very limited benefits and to only a small fraction of those expecting to profit from them. The plans afforded through companies, and directly paid for fully or in part by them, include:

1. Life insurance: group, with or without disability protection; regular life, with or without disability.
2. Pensions: company plans are often set up in addition to Social Security benefits. These plans may be promissory or actually guaranteed. The most secure plans are annuities placed with insurance companies.
3. Unemployment benefits: state plans under a federal plan. Benefits are limited. Mutual benefit associations of companies sometimes are a supplementary aid.
4. Workmen's compensation: compulsory under state laws, with specific benefits graded by nature and seriousness of accidental injury or occupational disease suffered by the worker.
5. Group hospital plans: provide for payment of hospital expenses and certain related hospital charges for the worker and his family. Sometimes the whole premium cost is borne by the worker.
6. Group medical plans: provide for payment of doctor's fees, etc., since these are not covered in the regular group hospital plans. Sometimes workers bear the entire premium cost.
7. Accident and health insurance: plans in addition to workmen's compensation, which provide for accidents and diseases not suffered as a result of employment. Not in wide use and usually paid for by employees. Mutual benefit associations often provide aid in such cases.

OTHER PROVISIONS TO SUSTAIN GOOD RELATIONS.—Besides economic security employees are, or may become, interested in many other factors of relationship with their company. Since a worker spends a net of about one-quarter of his total week's time of 168 hours in the plant, he builds up there many contacts and associations which, in a good company, often impel him to wish to broaden his connections with the company and his fellow-workers and their families in ways not directly concerned with his daily job. In a well-run organization, outlets are provided along such lines. A cardinal principle is, wherever possible, to place such matters in the hands of employee associations, clubs, or groups, and let them organize, administer, and carry on the activities. In this way the employees are doing the things themselves and they take personal interest in them. If the work is carried on by the company, it appears paternalistic and patronizing. Moreover, many active employees in this way expend constructive energies that otherwise might be turned to mischief, discontent, and disturbances, and they secure desired recognition and prestige which may not come to them on their jobs. Good morale thus often develops to replace a tendency toward hostility, insubordination, and other possible results of frustration.

Among the organizations, outlets and agencies for the development and maintenance of good relations are:

1. Financial aids.
   a. Mutual benefit associations organized and operated by employees.
   b. Savings plans.
   c. Credit unions organized for savings and loans, and run by employees but under government supervision.
   d. Loans or relief made available to employees.
   e. Stock distribution or stock purchase plans.
   f. Housing. Some companies rent houses to employees. Some aid employees to finance purchase of homes, or at least give advice on such questions.
2. Employee activities.
   a. Shop bands and orchestras.
   b. Choral societies or glee clubs.
   c. Dramatic societies.
   d. Athletic associations.
   e. Field days, picnics, etc.
   f. Dances.
3. Employee clubs.
   a. General association to handle a wide variety of activities.
   b. Special clubs or groups interested in specific features.
4. Employee services.
   a. Lunchrooms and cafeterias.
   b. Local lunchcounters with limited menus.
   c. Dispensers of candy, soft drinks, milk, salt, etc., in shop departments.
   d. Traveling carts carrying luncheons, sandwiches, cake, candy, soft drinks, milk, etc.
5. Employee publications.
   a. Monthly house organs.
   b. Weekly news sheets.
   c. Bulletin boards for employee services.
   d. Special booklets or pamphlets on company services, etc.

PAMPHLETS AND PUBLICATIONS FOR EMPLOYEES.—Since there is little time—outside of training classes, conference or committee groups, and departmental mass meetings—to get the spoken word to employees, and because it is desirable to convey messages and information to them on important matters in far better ways than trite bulletin board notices or the brief remarks of foremen to individual workers, there is need for carefully prepared and honestly worded pamphlets and publications provided by the company, in larger plants, to carry on this necessary work. The information may cover the relation of the worker with the plant and its work, safety handbooks, announcements of various plans for employee services, an explanation of the company's financial statements, a resume of the year's activities in the company and its economic and industrial advances and contributions to the public welfare, statements in regard to labor relations, and numerous other topics.

The following are typical booklets and pamphlets illustrating the field and coverage of such publications at the Allis-Chalmers plants:

Your Work at Allis-Chalmers (West Allis Works). (Industrial Relations, Collective Bargaining, Safety First, Shop Policies, Procedures and Rules.)

Safety Always at Allis-Chalmers.
Women Safe at Work at Allis-Chalmers. (An original pamphlet of its kind.)
The Open Door to Opportunity at Allis-Chalmers. (Training Division pamphlet explaining the many kinds of training available to company employees.)

The Caterpillar Tractor Co. likewise has carried the development of pamphlets to a high stage of efficiency. Among its booklets are:

Our Company. (Things You'll Want to Know, Cooperation, Safety, Employee Activities, Company History.)
Announcement of Employees' Group Insurance Plan.
Announcement of Employees' Group Hospitalization Expense and Surgical Benefits Plan.
Vacation Plan.
Here are the Facts to Arm You Against Rumor, Gossip, False Reports. (Answers to logical questions as to methods of operation under emergency war work.)
The Year 19—. (Twelve Months of Progress at "Caterpillar." Covers production, employee activities, health and safety, training, conservation, plant protection, employee contributions to welfare, plant development.)

Progress of labor relations negotiations has also been reported to employees in explanatory pamphlets.

Thompson Products, Inc. has a yearly "Employees' Handbook 19—," in the front of which is a perforated "Receipt and Certification" slip worded:

I hereby acknowledge receipt of the Employees' Handbook of the Cleveland plants of Thompson Products, Inc., dated January 19—. I recognize my obligation to read and thoroughly understand its contents, and to observe all policies and procedures.

Signed ....
Master Number ....
Date ....
[Note: This receipt to be filed.]

Included in the handbook are: lists of staff and operating executives, company president's message, outline of the company and its policies, wages and hours plan and seniority regulations, the "Old Guard Association," factory regulations, training programs, employee benefits, Recreation Club, Ex-Service Men's Club, plant publications (including a monthly Friendly Forum).

The company also issues an "Annual Report to Employees" summarizing the previous year's receipts and distributions. A cut-out arrangement of the successive pages as shown in Fig. 4, allows for the detailed explanation of each separate item, visible in the full statement, but actually printed on the succeeding pages where the items are respectively analyzed.

There are innumerable examples of excellent plant magazines (house organs) which feature important company developments, news, articles on executives or workers who are in the limelight, and abundant personal items, pictures of employees, and many other factors which induce all employees to go through the publications and become interested and

HOW TOTAL COMPANY INCOME WAS DIVIDED IN 19–

Our customers were charged for Parts and Services a total of			$87,003,208
Out of this we had the following bills to pay, not including wages or salaries	Taxes	$11,555,788	
	Materials	26,797,412	
	Depreciation	863,639	
	Other Expenses (Including Rent)	5,581,345	
	Total	$44,798,184	$44,798,184
This left to be divided between employees and stockholders			$42,205,024
The Division was made this way	1—Paid out in Payrolls—94.2%	$39,763,407	
	2—For Reinvestment in the Business—4.4%	1,864,057	
	3—Paid out in Dividends—1.4%	577,560	
	Total	$42,205,024	$42,205,024
		Balance	—0—

Net Profit for the year is equal to Item 2 plus Item 3, or $2,441,617.
This is a profit of 2.8% on total income.

Successive underlying pages, on which respective figures down the column are explained in detail, are indicated by dotted lines.

FIG. 4. Effective Form of Annual Report to Employees on Company Operations

informed regarding their contents. The closer such publications come to the everyday affairs and interests concerning the individual workers and relating to their company affiliations, the better. These house organs are read also in the homes. Good examples are the "Budgette" of the Edward G. Budd Manufacturing Co., and "Flight Control" of the Eclipse-Pioneer Division of Bendix, Inc. Weekly plant newspapers or occasional issues of such papers are likewise beneficial in keeping employees in touch with the company and its activities.

Industrial Training

THE TRAINING PROGRAM.—A training department is primarily a service organization assisting the company in meeting its obligations by providing a source of qualified employees. It teaches the employees what they need know to do and understand their work, it teaches them what they need know to advance, and it keeps a record of the progress of the individual employee in knowledge and skills as a basis

for possible promotions. The practice of expecting schools or other employers to do the work and foot the bill of developing workers to an acceptable stage of efficiency so that the individual company can pick them up without the responsibility and cost of training is neither sound nor ethical. The need for carrying on training exists in practically every plant and factory.

Industrial training must always be based on a specific need. Training is the process of imparting and developing knowledge, attitudes, skills, and habits necessary to performance of a specific industrial job or task. The question which should always be asked when a prospective training course is suggested is: "Is there a specific training need?" The use of a standard form such as Fig. 5 will help to define the need, and evaluate it.

REQUEST FOR TRAINING COURSE

DATE__________

To: Training Director

FROM:

Department__________
Supervisor__________
Type of training desired__________

Type of personnel involved__________
Number of personnel involved__________

The instruction requested to be given
(On Company time__________
(On employee's time__________
(Day shift__________
(Night shift__________

Where is the most convenient place for the instruction to be given__________

Possible agency involved__________
Specific need for the course (give details)__________

Specific objectives of course__________

DISPOSITION OF REQUEST

Training Agencies contacted__________Date__________
Record of conferences on training__________

Request for Course
(Approved__________
(Disapproved__________ DATE__________
BY__________

DATE COURSE TO START__________ BY Training Director

FIG. 5. Request for Training Course

Important Factors.—The selection, setting up, and carrying out of a training program is based on a few important factors (Fac. Mgt. & Maint., vol. 99):

1. Objectives.
2. Persons to be trained.
3. Kinds of training needed.
4. Agencies through which training may be given.
5. Methods of instruction.
6. Length of training period.
7. Instructors and their training.
8. Tests of accomplishment.
9. Costs versus efficiency developed.
10. Organization for training.

The objective of all industrial training is better to prepare individuals to do specific jobs within the organization. Industries are not colleges or universities and they cannot carry on broad educational programs for general development of the working force. But they can train persons to do work, or do it better, and they can train capable employees to go into higher jobs. So the training is, first, immediate, and, second, preparatory for advancement. Neither can be neglected. Immediate training is given to the workers and preparatory training to those who must be advanced into more responsible positions.

Rank of Employee	Kinds of Training
Inexperienced younger employees	Vocational Trade extension Cooperative Apprentice
New employees, regardless of age or experience, who must be taught jobs	Preemployment Preindustrial Vestibule school Orientation Trainee or learner taught by a worker Training on-the-job by an experienced trainer Training of women workers
Employees with some experience and perhaps educational background	Refresher Upgrading
Engineers or others technically qualified	Engineering and technical Graduate engineering
Supervisors and foremen	Training-within-industry Job instructor training Job methods training Job relations training Foremanship Supervisory Leadership
Executives	Management Organizational

FIG. 6. Groups of Employees Who May Be Given Training

Persons to be trained today constitute practically the whole range of the working force. Even experienced men and women on many jobs must learn the changed methods brought about by new technical procedures. The kinds of training needed vary with the age, experience, aptitudes, and jobs of the trainees. Invariably, in successful training, the emphasis is on the specific and not the general in subject matter. The tabulation in Fig. 6 blocks out roughly the groups into which available kinds of training may be classified (Fac. Mgt. & Maint., vol. 99).

Organized Training Not a Substitute for Line Training.—The effort to install new training methods under new leadership or to institute a broad revision of methods along up-to-date lines should be preceded by a thorough survey conducted by someone experienced in the adult vocational training field. Any analysis of training needs should be based on the important premise that, if centralized authority for general direction of training policies is to be recommended, delegation of authority for this purpose to the training department is primarily for the purpose of establishing suitable plans, procedures, and techniques for training activities. There should be no effort to remove from line officials the responsibility for supervision and daily instruction of their employees. The primary purpose of a training department is to assist those now doing training by providing improved facilities, suggesting better methods, and accomplishing these objectives under favorable conditions where the emphasis can be placed upon proper procedures rather than merely to maintain production regardless of how this is accomplished (Roy W. Kelly).

The ultimate duty of operating executives in regard to the training of employees is further emphasized by the modern practice of appointing an assistant to each foreman of a fair-sized department, whose sole work is to carry on line training to upgrade workers and improve the rate and quality of production in the department. This assistant reports to, and takes his orders from, the foreman, but receives advice, guidance, assistance, and training from the plant training director or personnel director. At the same time, many of the workers in the department may be receiving additional special training in groups under the instruction of the central training department.

The advantages of a centralized training program are: to place training costs on an open basis, to set a definite goal to be reached, to prepare progress reports, to arrange proper balance of classes without injuring production, and to maintain adequate control of company training. A specific training program should function to maintain costs at a minimum, and to take full advantage of municipal, state, and private educational facilities. Training is never an end in itself, but a means of meeting the company's obligations and commitments.

CONTROL OF THE TRAINING PROGRAM.—All education in a company should be under the training program. All instruction should be regarded as training, whether on the job or off the job, whether for one lecture of an hour's duration, or for two or more years' instruction on the college level.

The training department must be responsible to a high official in the organization, since its functions carry it into every department. The training director must have authority to establish training. He must

conduct surveys to determine and ascertain the necessity for training in various departments. He must establish company standards, approve applicants for classes, establish the length of courses and sessions, and choose the instructors. The material to be covered in any course must be evaluated by the director, in conference with department heads, instructors, and other interested parties. In certain cases, he is charged with the development and approval of class training manuals. He is responsible for securing the most effective educational devices, such as visual aids, instructional charts, and data books. His office may also act as a clearing agency for all inquiries in the company and outside sources relative to industrial training programs. He is responsible for the acquisition and dissemination of all training material concerning the company and outside sources. He may also institute training with various educational institutions where needs are justified in order to assure an adequate labor supply.

He is the person responsible for the operation of training designed to meet the requirements and needs of shop, office, technical, and supervisory personnel, embracing the following: vocational training (preemployment, preindustrial, orientation, apprenticeship, and supplementary training for factory and nonfactory employees), maintenance and operation training, supervisory training (foremanship, supervisory and executive training, Training Within Industry series, and round-table conferences), passive defense training, sometimes subcontractor training, instructor and conference leader training in conjunction with the departments concerned, and where deemed necessary, and other courses to cover demonstrated needs.

GENERAL LIMITATIONS OF A TRAINING PROGRAM.—The training department has been designated a service organization. If it cannot earn more than its own cost by improving production, it should be discarded. Accordingly, it should act on specific tasks only and not attempt to conduct training unrelated to company work and objectives. There are many obvious jobs for the training department of any company. Specific needs for training can be detected by such evidences as:

1. Failure to meet production schedules.
2. Poor safety record.
3. High rate of spoiled work.
4. Lack of cooperation, or poor morale.
5. High costs.
6. Rapid turnover of labor.
7. Scarcity of qualified applicants to fill vacancies.

The impetus for a training course or courses to correct such situations may come from the department head or executive concerned, or may be uncovered by the training director. Usually the specific training needs are not obscure. On the contrary, there are usually more requests, formal or informal, than can readily be filled. In selecting training courses for his company, it must be the duty of the training director to decide where training will do the most good, and help most to improve or increase production.

Physical Limitations.—Space must be available in an accessible place for the training. There are many possibilities to consider in selecting the location where the instruction is to be given.

Training may be carried on:

1. In the plant by company instructors.
2. In outside schools and facilities.
3. On company property in conjunction with outside agencies.

The possibility of taking the training to the employees must not be overlooked if it will bring a ready solution to the problem. Such a plan may even involve holding classes outside in some place convenient to the majority of the persons to be trained.

If a course for, say, milling machine operators is contemplated, careful consideration should be given to utilizing, as the nucleus of a school, any machines in the factory that may be idle, with a company instructor or one brought from the outside. Since trade schools are frequently limited in amount and variety of equipment, the training may be speeded up by utilizing both shop and school equipment. As soon as the trainees are sufficiently advanced, the machines used may be returned to productive work.

Psychological Limitations.—Almost every training class presents a problem of mixed mental capacities. There is no time for the leveling of personnel. The instructor must never be allowed to forget this fact in preparing and presenting his material. The course of study must be specific, and the instructor must be certain that every person covers and understands all the material required for the job. The advancement of the group as a whole is his primary teaching assignment, rather than the spectacular development of a few individuals.

Class hours must also be given careful consideration. If the instruction is given off company time, the sessions may be confined to two per week, of not over 2 to 3 hours duration each. If working hours are excessive, perhaps one session is all that may be scheduled, but more than 2½-hour sessions should usually be avoided, since workers are not capable of concentrated attention for long periods. Short sessions, about one hour long, are often far better. Shop-work classes, however, may run as long as 4 hours.

It has also been found that classes scheduled early in the week are more successful than those arranged for late in the week. Friday and Saturday classes should be avoided whenever possible, except perhaps for one-session classes.

If the training course is to be given on company time, classes should be scheduled for early in the day. Two hours after starting work is an ideal time for a class to begin. A second choice is for a period beginning one hour after lunch. Classes given off company time for night-shift employees are usually scheduled for a period immediately before their starting time, with approximately one-half hour leeway between termination of the class and beginning of work. Off-time classes for the day-shift start immediately after the termination of the working period, with only a short time allowance for some refreshment. In the case of intensive industrial training, a full day of schooling may be scheduled, but the instruction should be divided into class periods and shop practice or laboratory experiments, so that there is a balance of each in the morning and afternoon sessions. Two sessions of machine work, for example, may be separated by a class hour of mathematics or a talk on safety.

Existing Facilities for Training

AVAILABLE AGENCIES.—The agencies through which these various kinds of training are given, or from which aid in organizing and conducting the training may be secured, are as follows (Fact. Mgt. & Maint., vol. 99):

1. Local schools (local boards of education).
   a. High schools.
   b. Technical schools.
   c. Vocational schools.
   d. Evening schools.
2. Colleges and universities.
   a. Day or evening courses. Admission to single evening courses as well as complete degree-giving courses is available in practically all college and university centers.
   b. Courses given by university extension divisions at the universities and in industrial centers throughout the various states.
   c. Special courses conducted within industrial plants by colleges and universities.
3. Technical institutes.
4. State departments of education.
5. Federal agencies such as the U. S. Office of Education and the War Manpower Commission Bureau of Training.
   a. Training Within Industry.
   b. Apprenticeship Training Service.
   c. Vocational training as aided by the U. S. Office of Education.
6. Training through private agencies.
   a. Resident
      (1) Trade-school courses such as those giving instruction in welding, machine-shop practice, airplane repair and servicing, etc.
      (2) Training given in plants or in special outside groups by certain consulting management engineering organizations which conduct courses in production management, personnel relations, and other subjects of plant operation.
   b. Nonresident. Courses in special subjects offered by home-study or correspondence institutes and schools.
7. Industrial service bureaus, or central training agencies of individual industries (such as the Manpower Division of the Automotive Council for War Production).
8. Institutes or schools of individual companies (Goodyear, Ford, General Motors, Chrysler).
9. The training department of the individual plant.

LOCAL SCHOOLS.—The local board of education is the first source to examine for aid in preindustrial and preemployment training, as well as in supplementary training. Vocational schools and evening schools are specially equipped to give useful training. The aid of the local school system may be enlisted to write a curriculum, in conference with the training director and members of the shop personnel. This plan will save time and money for the company.

Trade extension courses are sometimes arranged with local schools, that is, younger workers still within school age secure jobs but are released for certain hours to continue their school education. This plan has also been known as the **continuation school plan.**

COLLEGES AND UNIVERSITIES.—Closer correlation has come about in the past few years between colleges and universities and the industries which need among their employees not only fully trained college graduates but also employees who require specialized information and training in certain subjects on the college level. The vast use made recently by the federal government of college facilities for the special training of noncollege industrial employees has awakened the colleges to the importance of such service and industries to the benefits to be derived from these organized and efficient training facilities.

Some colleges, and the institutes established by certain leading companies, carry on **cooperative training,** that is, the students spend alternate periods in classes and then in the departments of an industrial plant, to gain practical operation experience while they are acquiring theory through education.

TECHNICAL INSTITUTES.—A number of technical institutes have been established in recent years. They give high-grade training adapted to the needs of industries and offer a valuable source of development of high-grade men qualified for the higher skills and for supervisory and foremanship responsibilities.

STATE DEPARTMENTS OF EDUCATION.—Many other services are available through the state departments of education. The rehabilitation services of most states are constantly on the lookout for employment opportunities for persons under their care. Companies may investigate the opportunity of having such persons trained for specific jobs in their shops. Milling machine hands, welders, engine-lathe operators, etc., have been trained for many companies in a number of states at state expense. The company outlines the need for workers and promises to hire qualified persons trained to fill the need.

FEDERAL ASSISTANCE.—There are a number of ways in which the federal government stands ready to assist in training programs. This assistance is usually available without expense to a company.

Training Within Industry.—Training Within Industry was first evolved in three parts—job instructor training, job methods training, job relations training—three courses of 10 hours' duration each, and was an outgrowth of federal assistance. It became an effective way of reaching the greatest number of people in the shortest amount of time. The application of these methods was actively carried on first by Glenn Gardiner, as District Director within New Jersey of the Training Within Industry Service, who developed details of the job instructor program, and Clifton Cox, who, as a member of the New Jersey District staff, developed details of the job methods program.

Job Instructor Training.—J.I.T. is a 10-hour course which aims to train instructors to show others how to do various jobs. It is based on the premise that the average supervisor has plenty of "know-how," but often just does not put this information across to his workers. It works on the premise that if the pupil hasn't learned, the teacher hasn't taught. J.I.T. gives the supervisor a pattern of thought to use when teaching an operation, so that he may be sure that he does a thorough job of instructing the workers under his care. Most of the training is concentrated on methods of demonstrating how to do work.

Job Methods Training.—J.M.T. is another 10-hour course to promote the more effective use of available men, materials, and machines. The questions asked about every operation in the shop revolve about "why," "what," "where," "when," "how," and "who." Surprising and almost unbelievable gains have been reported in numerous plants from application of Job Methods Training. Each worker is taught to analyze his job, list every operation, question its necessity, and perhaps through this questioning, eliminate waste motion and save time.

Job Relations Training.—J.R.T. teaches supervisors, in a 10-hour course, how to get along with the workers under their supervision. It is a basic course in human relationships. Like the other parts of the program, its success has been widespread.

Program Development Training.—P.D.T. develops a complete training program for an industry, and is a fourth "packet" with the three "J" programs.

Training Within Industry is admittedly a quick course in supervisory training, but its value to industry has been widespread and great in spite of its brevity and concentration.

Apprenticeship Training.—Another aspect of training is the promotion of a long range apprenticeship program through the Apprentice Training Service of the federal government. This kind of training is often overlooked today. However, there will always be a need for skilled mechanics with all-round training to provide the necessary new foremen, skilled tool and jig makers, etc.

Certain states are also ready to provide apprentice training aid. The state director of vocational education stands ready to help any company in his district.

Procedure for Establishing a Training Course

PATTERN FOR INSTITUTING A COURSE.—The following procedure may be used as a pattern for a training course (Leonard Weiss, Richard Everill, and Peter Lubin, Aero. Engr. Review):

1. A form letter (Fig. 5) should be sent for filling out to the supervisor of each department where training is contemplated. This form will provide a statement of the objectives of the course for future reference.
2. The training director or his representative must decide with the supervisor the level of instruction and the possible sources which may be used to give the instruction, i.e., the public school system, the Training Within Industry program, class sessions, etc.
3. Contact is made with the various agencies concerned. In the case of the public school system, a letter should be sent to the superintendent requesting assistance in instruction in a particular field. In any case, the end result must be a practical course for company employees, specific in content, clear in objective, and making use of company materials as samples wherever possible.
4. Company approval must be secured. The training director should be certain of the specific value and need for a course before arranging for on-time instruction. He must always be doubly cautious if the instruction is likely to involve the payment of overtime for trainee time spent in classes.

S-832
MASTER REF.
PAGE NO.
ITEM NO.

REGISTRATION CARD

(PLEASE PRINT) | HOME ADDRESS

LAST NAME | FIRST | MIDDLE | STREET NO. | BORO | CITY

DEPT. NO. | DEPARTMENT NAME | DEPARTMENT HEAD (NAME - TITLE)

CLASSIFICATION OR TITLE | CLOCK NO. | SHIFT | LOCATION OF INDIVIDUAL | TEL. OR EXT. NO

NAME OF COURSE | CONDUCTED BY (ORGANIZATION) | INSTRUCTOR

MEETING DAY | TIME | LOC. | RM. NO | MEETING DAY | TIME | LOC. | RM. NO. | MEETING | TIME | LOC. | RM. NO

MEETING DAY | TIME | LOC. | RM. NO. | MEETING DAY | TIME | LOC. | RM. NO. | MEETING | TIME | LOC. | RM. NO

GROUP NO. | STARTING DATE | COMPLETION DATE

S-832 CONFERENCE SCHEDULE

NAME | COURSE | GROUP NO.

ATTENDANCE RECORD CODED P-PRESENT A-ABSENT DROPPED E-EXCUSED

CONFERENCE NO.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

DATE CONFERENCE SCHEDULE

DATE ATTENDED

NO. OF HOURS IN SESSION

ABSENCE NOTIFICATION - (1) REF. (2) DATE

2

TOTAL NO OF ABSENCES | PER CENT OF ATTENDANCE | TOTAL NO. OF HOURS ATTENDED

QUALIFIED FOR CERTIFICATE | YES | NO | DATE RECEIVED

REMARKS

FORM NO.

FIG. 7. Registration Card for Training Courses (*face and reverse*)

5. The class schedules should be drawn up in conference with the supervisors of the departments concerned. Particular attention must be paid to the arrangements of classes so that the personnel of a particular department is not taken in a group to class, leaving the department stripped of an adequate productive working force.
6. Notices should be sent out stating class hours and location of classrooms. Personal notices should be sent to each individual invited to attend; special notice should be sent to supervisors.
7. Registration and attendance cards, such as Fig. 7, are to be made out for the class, using standard forms.
8. Class attendance sheets (Fig. 8) should be made out for each session.
9. When the course is completed, each student should be given recognition for his work, in the form of a certificate of traditional size. Some companies also supply a small card certificate which may be carried in a wallet.
10. A notice, such as Fig. 9, is to be sent to the personnel records section of the personnel department and each respective supervisor, when

ATTENDANCE SHEET

COURSE________ GROUP________ DATE________

CONFERENCE TITLE________ CONFERENCE NO.________

MEETING LOCATION________ ROOM NO.________

TIME CONFERENCE STARTED________ TIME ENDED________ TOTAL HOURS________

NO. SCHEDULED________ NO. ATTENDED________ NO. ABSENT________

SUGGESTIONS OR REMARKS________

CONFERENCE LEADER________

ATTENDANCE SHEET

NO.	NAME	SIGNATURE	CLOCK NO.	REMARKS
1				
2				
24				

FIG. 8. Attendance Sheet for Training Classes (*face and reverse*)

the employee has successfully completed a training course, such information to be incorporated in the employee's personnel record and file.

11. A follow-up should be made of the trainees who have completed a particular course. The purpose of this follow-up is to find out if the course was practical, to determine its limitations, and to formulate ways for its improvement. The follow-up may be by: (1) questionnaire to each individual, (2) conference with all or some of the successful trainees, (3) personal contact with employees on the department floor, or (4) personal contact with supervisors.

REPORT ON TRAINING COURSE COMPLETED

DATE________________

To: Personnel Records

FROM: Training Director

This is to inform you that:

NAME________________ CLOCK NO.________________
DEPARTMENT________________ CLASSIFICATION________________

has completed a Training Course on________________

TITLE OF COURSE________________
GIVEN BY________________ TOTAL HOURS________________
FOR________________WEEKS, ________________SESSIONS PER WEEK,
________________HOURS PER SESSION.

THIS COURSE WAS GIVEN ON Employee's / Company time.

Will you please see that this information is added to this employee's permanent record.

____
Training Director

FIG. 9. Report on Training Course Completed

NECESSARY RECORDS.—The original registration cards (Fig. 7) can be filled out in duplicate by each trainee. All information necessary for the two records mentioned above should be called for on these cards. One card can be filed by individual course, the other card can be filed alphabetically by last name of trainee. The file of cards, by course, is maintained in active and inactive sections. When an employee finishes a course, his card is transferred from the active to the inactive section. When he registers for another training course, however, he need fill out only one card instead of two. This card is to be placed in the active file section, by course, and is to be used as a basis for making notation on his original registration cards filed alphabetically according to his name. A running attendance record is to be kept on the back of the card filed by course. Attendance sheets (Fig. 8) should be signed by each student, and can be prepared singly, or in duplicate and triplicate if necessary for a variety of purposes.

Notification of the employee's completion of a course (Fig. 9) is the final individual record prepared and sent to the personnel department.

Two basic records serve as the backbone of the personnel department's

COURSE NO ——— NAME ——— CONDUCTED BY ———

GROUP NO ——— SESSION

	MONDAY AM-PM	TUESDAY AM-PM	WEDNESDAY AM-PM	THURSDAY AM-PM	FRIDAY AM-PM	SATURDAY AM-PM	SUNDAY AM-PM
DAYS							
HOURS							
REVISION							

ITEM NO.	MASTER LIST OF PERSONNEL SELECTED		DEPART'MNT		CLOCK NO	NAME			SEX		DEPARTMENT NOTIFICATION OF TRAINING SCHEDULE			INDIVIDUAL NOTIFICATION TO ATTEND CONFERENCES			
	PAGE NO.	ITEM NO.	NO.	NAME		LAST	FIRST	INITIAL	MALE	FEMALE	MEMO: SENT C.C. TO DEPT HD	MEMO: ACKNOWLEDGED	PHONE CALL VERIFICATION	MEMO: SENT	MEMO: ACKNOWLEDGED	PHONE CALL: VERIFICATION	
											REF	REF	DATE	REF	REF	DATE	NAME
											DATE	DATE	NAME	DATE	DATE		
											R						
											D						
											R						
											D						

CONF NO.	1	2	…	20	TOTAL HRS ATTENDED
DAY					
MONTH					
YEAR					
ROOM LOC					
INSTRUCTOR					
CODE					
HOURS IN SESSION					
CODE					
NO OF HRS					
CODE					
NO. OF HRS					

CODE ✓ PRESENT A-ABSENT D-DROPPED X-LATE E-EXCUSED

COST				ABSENCE FOLLOW-UP					DROPPED FROM CONFERENCES			CERTIFICATE OF COMPLETION						FOLLOW-UP QUESTIONNAIRE ON CONFERENCES FOR RESULTS AND SUGGESTIONS				SPECIAL IDENTIFICATION BADGES FOR TRAINING ACTIVITIES			REMARKS	ITEM NO
RATE OF PAY PER HR	TOTAL HRS TIMES RATE	OVERHEAD	TOTAL COST $	CONF NO	REF	DATE	REF	DATE	REASON	NOTICE SENT		RECEIVED FROM ORIGIN		IN PROCESS		PRESENTED TO INDIVIDUAL						BADGE NO	DATE ASSIG	DATE RET'D		
										REF	DATE	REF	DATE	REF	DATE	REF	DATE	REF	DATE	REF	DATE					

FIG. 10. Detailed Record of Trainees by Kind of Course

PERSONNEL LIST APPROVED FOR TRAINING CONFERENCES

DEPARTMENT HEAD ______
DATE APPROVED ______
TRAINING DATE DIRECTOR APPROVED ______

DATE OF ISSUE	REVISION LETTER	DATE	BY	COPY SERIAL*	ISSUED TO

MASTER LIST OF PERSONNEL

DEPARTMENT NO. ______

ITEM NO	REMARKS	CLOCK NO.	NAME			DEPARTMENT OR SECTION		SHIFT		TITLE PRESENT POSITION			
			LAST	FIRST	INITIAL	NO.	NAME	DAY	NIGHT				OTHER

SELECTED FOR CONFERENCES

NAME ______

SENIORITY DATE		APPROXIMATE NO OF EMPLOYEES SUPERVISED	LOCATION OF INDIVIDUAL					NEAREST TELEPHONE EXTENSION	TRAINING COURSES ATTEN[DED]						MASTER PAGE NO. REF.
									COURSE		COURSE		COURSE		
ORIGINAL EMPLOYMENT	OF PRESENT POSITION				"		OTHER		DATE COM-PLETED	SEE DETAIL SCHEDULE PAGE NO.	DATE COM-PLETED	SEE DETAIL SCHEDULE PAGE NO.	DATE COM-PLETED	SEE DETAIL SCHEDULE PAGE NO.	ITEM NO.

FIG. 11. Record of Trainees by Departments

permanent file of information on training: (1) record of trainees by course, (2) record of trainees by department, and (3) individual records in individual personnel folders.

The **record of trainees by course** (Fig. 10) consists of folders for each individual training course. Every course folder lists such essentials as the name of each trainee, clock number, job classification, department number, and attendance by date. This record immediately indicates which persons took what course—where—and at what time.

The **record of trainees by department** (Fig. 11) consists of a series of folders by departments. Each department folder lists the persons of that department who have completed one or more training courses, reference code number of each course, trainee clock numbers, job classifications, total attendance in man-hours for each course, rates of pay, and course grades. This record immediately indicates which persons in a department took what courses—where—and when.

The **records of individual progress** are important in considering individual employees, no matter what personnel action is proposed.

COSTS.—Each request for training should be examined to see if it can justify the expense involved. Although sometimes the instruction may be obtained without direct cost, there are always overhead costs to be considered. If the course is to be given on company time, a company policy must be established about charging employees' time to training. Perhaps the time of student will be charged to training for the class hours only; perhaps it will have to be charged from the time he leaves the job until he returns. Rules covering overtime rates are necessary.

Almost all preindustrial and preemployment training can be obtained through the state vocational education department. Vestibule training may be secured from the same source. Supervisory training can be obtained through the state universities, and such agencies as the Industrial Service Bureau of the State of New York.

TRAINING DEPARTMENT RECORDS

TRAINEES FROM DEPARTMENT ____

NAME	CLOCK NO.	COURSE CODE NO.	PERIOD			PERIOD			TOTAL
			TOTAL HRS.	RATE /HR.	TOTAL COST	TOTAL HRS.	RATE /HR.	TOTAL COST	HRS. COST
TOTAL ____ EMPLOYEES									

Fig. 12. Cost Record for Training Department

Visual aids may be obtained from the state or the U. S. Office of Education. Thousands of dollars can be saved by a company if an alert training director gives careful study to the excellent free services available through the various federal, state, and municipal facilities.

The company accounting department should accumulate all training costs by individual courses. It should also submit monthly statements (Fig. 12) of actual costs to the training director for comparison and study purposes. The accounting department, on the other hand, should be supplied with pertinent data on all purchase orders and factory orders for books, equipment, visual aids, etc., submitted by the training department.

OVERTRAINING.—Overtraining, or training beyond the reasonable limits defined by the training need, is both wasteful and a source for poor morale and discontent. For example, it would be uneconomical to encourage 20 persons to take a course in tool design if present and future needs indicate a maximum utilization of 10 tool design trainees. By the same token, it would be inexpedient to train, say, 25 assemblers in blueprint reading, if their work is preplanned, highly mechanized, and does not require blueprint reading. A hope would have been installed in each person that, upon successful completion of the training course, a better job or higher pay perhaps might be forthcoming, and the disappointment that might follow when the majority are unrewarded and only a few are advanced would offset a great deal of the values derived from the course. A survey of available jobs should be an important part of the first conference devoted to a particular need.

EQUIPMENT REQUIRED.—The equipment required by the training department is largely of a standard nature. An adequate number of classrooms is a basic necessity. The number of rooms required must be determined by a careful study of the present and projected needs of the program. Adequate administrative space in the proximity of the classrooms is desirable, though not absolutely required. If possible, the rooms should be near the shops, but quiet, well-lighted, and ventilated.

The equipment of each room should include blackboard space and side-arm chairs, or tables with chairs for the trainees and a desk for the instructor. Additional equipment will depend on the nature of the courses. One or two of the classrooms may be arranged for conferences, which are the most desirable form of instruction to use in supervisory training. The conference room usually has a quadrangle of tables, seating perhaps a maximum of 20 persons.

A suitable projection room, as well as equipment for projecting motion pictures, is an important part of the training department equipment. If a special projection room is impossible to obtain, some of the regular classrooms should be properly equipped with light-proof window shades and projection screens for showing moving pictures and slide films.

Laboratory space and equipment will depend on the nature of the training course offered. In many instances this sort of equipment may be secured from a local vocational school. Where there is vestibule training, effort should be made to keep the vestibule school equipment and methods up to date.

Instruction Pamphlets.—Companies that carry on extensive training work of a specific nature often develop their own pamphlets for instruc-

tion purposes. Representative of the nature and subject matter of such pamphlets are the educational bulletins of the Allis-Chalmers Co., among which are:

No. 3 – Slide Rule.
No. 4 – Rules and Practices for the Application of Electrical Insulation Coil Taping.
No. 5 – Weights and Measures.
No. 6 – Fractions and Decimals.

An Outline for Industrial Training

PREEMPLOYMENT TRAINING.—Preemployment training is that training made available through the use of facilities, public and private, before an individual is hired as an employee of the company. The curriculum is prepared by the school in consultation with the company to fit the specific job requirements. When the course is completed, the trainee is hired by the company, and brought into the production department, or into the vestibule school.

PREINDUSTRIAL TRAINING.—Preindustrial training is considered to be that of a preliminary nature administered to employees of the company both on the job and through the use of outside school facilities. The trainees are paid regular starting wages in accordance with the prevailing rates. The courses are selected and administered by the company and schools concerned. After satisfactory completion of these courses, the employees report for regular work at the plant.

Some training prior to employment helps shorten the time needed for developing skill on the job. With preindustrial instruction, the new employee learns the new job more quickly. He adjusts himself more readily to factory surroundings. He understands the language of the factory and, more important, he acquires beginner's skill.

Preindustrial training is most valuable when it is closely related to the job that the employee will fill. When pointed toward a specific job, it has greater appeal and the student is more eager to learn. The result is better training. The chief purpose of instruction in advance of actual work assignment is preparation for factory life. With its help, the beginner becomes acquainted with the tools, the machines, and the materials employed in his job and with routines and safeguards in common use.

A typical course of preindustrial training for an airframe manufacturer would be Riveting and Assembly. Such a course might be drawn up according to the following outline:

Place	Subject	Time in Hours
Lecture	Shop regulations and procedure. Safety rules	3
Shop	Use of hand tools, hand drills, drill jigs	5
Lecture	Handling of material. Files and hacksaws	1
Shop	Use of templates in production work	7
Shop	Fabrication of fin skins and stringers	8
Shop	Fabrication of rib section	8
Lecture	Care and use of motor-driven drills and countersinks	1
Shop	Fabrication of rivet plate (practice in use of air and electric drills)	7

Place	Subject	Time in Hours
Lecture	Drill sizes and fastening devices	1
Shop	Stringer assembly	7
Shop	Fabrication of a spar	8
Lecture	Use of jigs in assembly	1
Shop	Fabrication of beam assembly	7
Lecture	Taps and reamers	1
Shop	Fabrication of steel fitting	7
Lecture	Wrenches and fasteners	1
Shop	Fabrication of bolted beam section	7

VESTIBULE SCHOOL.—A vestibule school is used by companies which must train large numbers of workers in intricate skilled or semi-skilled jobs. It is a training department, separate from the regular production departments, where special instructors teach new or transferred employees the processes to be performed on jobs which these employees are to fill. Sometimes a limited amount of academic instruction, or information about the work or business of the employing company, is included.

Vestibule training may be the natural consequence of either a preindustrial or preemployment training program. Assuming that the trainee has acquired the basic background knowledge in such a program, he is brought to the company vestibule school off the production line for final training before going on production work. A section of the production shop is usually designated as the vestibule school. Instruction may be carried on by company or outside instructors. The trainee is given work to do that is primarily practice, but may be a part of production work. As his training progresses, he does more and more productive work. When he is ready, he goes into the production department as a worker.

The advantage of this kind of training is obvious. It provides the necessary follow-up for the preindustrial training. Regular production is thus not impeded by learners. Many trainees suffer stagefright when they pass from school to production shop, and the guidance of the vestibule instructors helps them over this obstacle. There is closer supervision over the trainees and special attention can be given their weak points. The results are better adjusted workers, and a lower turnover among the trainees.

SUPPLEMENTARY TRAINING.—Supplementary training includes training for both factory and nonfactory jobs. The training may be conducted: (1) in the plant by company instructors on company time; (2) in outside schools and facilities, on or off company time; (3) on company property in conjunction with outside agencies, on or off company time.

These courses may vary in length and frequency of session as the needs are demonstrated by the departments concerned. For instance, one course may last for only one hour and then be permanently discontinued, while another course may last for 20 weeks and be repeated over a long period.

Training in the essential skills of a job is best done on the job, but the supplementary information which is a tool for a beginner's job is most frequently acquired off the job. Supplementary training is applicable at all levels of the organization, and a necessary requirement for moving from one stage to that above. Time is wasted, and so are skills,

if management does not encourage employees to follow up their earlier training with off-the-job instruction, and integrate it with progression on the job.

The plan for supplementary training in any company should include courses for all departments, production and service, to cover all the needs. It is a common error to pick courses for the supplementary training program without giving much thought to the need for the courses. For example, almost everyone presumes that blueprint reading is a "must." But it is the studied opinion of some training men that this subject has been vastly overplayed. Today there are fewer jobs that require the worker to use prints than there were a short time back.

In some factories, courses for shop clerks, tool-crib attendants, and production control clerks may do more to improve and increase production than a dozen courses in blueprint reading. A typical list of a few useful courses will serve to illustrate the scope of a supplementary training program:

1. Production planning and control.
2. Basic inspection practices.
3. Lofting and layout (airplanes, shipbuilding, etc.).
4. Tool, jig, and fixture design.
5. Applied descriptive geometry.
6. Fundamentals of engineering practice.
7. Stress analysis.
8. Tool planning and operation-sheet writing.
9. Expediting.
10. Time study.
11. Work simplification.
12. Job estimating.
13. Office procedures.
14. Job evaluation.
15. Labor relations.

APPRENTICESHIP TRAINING.—Because the number involved is relatively small, the apprenticeship program is frequently forgotten in the hurry to train for jobs that require little skill. But the training of replacements for the thinning ranks of master craftsmen is an important point to be considered by any company that hopes to continue in business. When the natural course of worker separations takes its toll of toolmakers, expert maintenance men, and the like from the shop, replacements cannot be trained to take their place in 60 days, or 6 months. When the older foremen retire or die, it becomes a difficult task to find men to take their place.

Skilled maintenance men are often as difficult to find as skilled shop men. The answer to such problems as these will be found in a well-planned apprenticeship training program. This program should run constantly, even though the difficulties of finding applicants and retaining them may sometimes seem insurmountable. It should include a course for millwrights and other maintenance men as well as machinists. The future needs of the company should be considered at length, taking into full account such factors as the age level of the supervisory staff and the skilled craftsmen in the shop.

Other adjustments must be made. For example, it is extremely difficult to find young men who will enter an apprenticeship agreement if it is written on the conditions that existed a few years ago. Today, to make the program attractive, it may be necessary to offer almost the

basic wage rate in the shop. While this change will cost the company money, it will at least encourage the applicant to enter a long and intensive course of training. In addition, the course of instruction must be shortened from the traditional four years to three, and perhaps even less. The possibility of utilizing girls or young women must not be overlooked and, if care is used in selecting the applicants, many of the obvious objections may be dismissed.

SUPERVISORY TRAINING.—The objectives of the supervisory training program are to teach those members of the company who are in supervisory positions the fundamentals of supervision and of human and industrial relations, and to provide them with an understanding of the policies, plans, methods, and problems of management.

Foremanship and supervisory training courses should be given to all foremen, assistant foremen, and subforemen, to department heads and supervisors, and to leadmen and group leaders. A sound policy is to provide that all men raised to a supervisory capacity be given a course of basic training immediately, and that refresher courses be given from time to time.

Supervisory training may be divided into the following general classes:

1. Foremanship.
2. Specific supervisory.
3. Executive.

Foremanship training is concerned largely with teaching men the elements of proper supervision, the basic skills of instruction, and the art of human relations. It attempts to give each man in a supervisory capacity a background for dealing with the problems that concern him as a supervisor, but which perhaps never concerned him as a worker.

This training is usually given by means of the conference method, with the group ranging from 12 to 18 men in larger plants. A training conference leader conducts the course, discussing a selected list of topics. Such a list would probably include:

1. Responsibilities of the supervisor.
2. Avoiding wasted time.
3. Maintaining discipline.
4. Handling grievances and relations with unions.
5. Getting the best out of men.
6. Giving orders.
7. Accident prevention and safety.
8. Planning.
9. Job analysis.
10. Methods improvement.
11. Cooperation.
12. The supervisor as instructor.
13. Understudies.
14. Care of materials, tools, and equipment.
15. Waste reduction.
16. Plant housekeeping.
17. Interpretation of company policies to workers.
18. Leadership.

A suggested course would last about 20 weeks, with one session of an hour and a half per week.

Specific supervisory training would be confined to a discussion and development of the general topics as they affect a particular phase of

industrial work. All examples would be drawn from the specific departments with which the supervisors are affiliated. An illustration of this type of training is personnel management and industrial relations for personnel supervisors.

The conference and group discussions methods have certain inherent dangers which will be emphasized when these methods are applied to specific supervisory training. First, the discussion may develop along general lines instead of specific company problems. Second, the conferences may easily degenerate into "gripe sessions." The specific supervisory training course must include the lecture and case methods if it is to be effective.

The value of supervisory conferences may be manifold. Company policy can be developed or defined through the conferences. Increased cooperation between shifts or departments should be a natural consequence.

The Training Within Industry program has a definite place in this supervisory training program. It may be used as an introductory course when a man is first advanced to a supervisory level. Later, the slower, broader course of foremanship or specific supervisory training may be given.

TRAINING FOR PRODUCTION PLANNING.—The widespread recognition of the production planning and production engineering departments as vital factors in modern streamlined, mass-production, low-cost operation has given rise to the need for specific training in this field. Such training is given mainly to three groups—men who are connected with one of the many divisions of production planning or production engineering activities, men who are in supervisory, foremanship, or other responsible positions in the operating departments, and a third group of men from the personnel, cost, purchasing, materials control, and other staff or service units whose work requires that they have a knowledge of this subject. In university centers courses in these subjects are offered to nondegree students, and certain consulting organizations have developed courses for plants or public groups in places where such college training in these special subjects is not available. Plants having highly developed production control departments sometimes conduct inside courses in which the instruction is given by department members doing such work. Subjects which may be covered include:

- Factory organization
- Production planning
- Production control methods
- Production control systems
- Time study and operation analysis
- Motion study or work simplification
- Materials control and storeskeeping
- Methods engineering
- Manufacturing processes
- Tooling for jobs
- Plant layout
- Materials handling
- Inspection
- Wage plans
- Job evaluation

Members of the various units of production control departments often are not acquainted with one another's work and sometimes operate at cross purposes. Many of the men know only their own special kind of activity and have no knowledge of the relationship of their function with other functions. Instruction brings the separate units into an integration and coordination of activities which greatly simplifies operations and increases the efficiency and success of all production planning and

control procedures. Men from the shop learn what is done in production planning and coordinate their performances in closer harmony with such plans as a result. Members of the cost, purchasing, and other departments learn to work out methods whereby the production control and operating departments are enabled to collect and supply the important production information needed by these other departments.

EXECUTIVE TRAINING.—Supervisory training conducted on a higher level becomes executive training. Where the foremanship training emphasizes the human relations aspect of the supervisor's job, and aims to develop instructional skill, executive training is concerned with broader problems, largely in the field of industrial management and engineering. In addition to the topics suggested above, the following can be included: quality control, merit rating, industrial relations, industrial psychology, collective bargaining, policy development, and management factors or the "management formula." This training could be conducted by means of the conference and the group discussion methods.

ROUND-TABLE CONFERENCE PROGRAM.—The round-table conference program, which is often used, consists of a series of special conferences on selected subjects. A planned agenda should be used in all cases. A conclusion should be reached, or specific action taken, as the result of each conference.

These conferences may be a connected series continuing each week, or may be only for an hour or so, convened upon a demonstrated need. Typical subjects to be discussed would be: the union contract, company policies and procedures, employment problems, etc.

PASSIVE DEFENSE TRAINING.—Training of a protective and preventive nature is known as passive defense training. It includes:

1. First aid.
2. Guard training.
3. Fire brigade training.

The training in these subjects is usually done by the department immediately concerned with the supervision of such services within the company. The company medical service department is the natural agency to give instruction in first aid, although it may call upon the Red Cross to conduct the courses. The guard training is usually police practice specifically applied to the company problems. The company fire marshal or men of the city fire department may be utilized for training the volunteer employee fire brigades. This latter course may be conducted in some cases as the need arises, or regularly in others, depending upon local requirements. Guard training may be given whenever the number of new men is sufficient to warrant a class. First-aid training may be given regularly once a week.

SUBCONTRACTOR TRAINING.—The training of subcontractors is usually overlooked. Since most large corporations today depend, in part, upon subcontractors for deliveries of parts and assemblies, provision should be made to reach the members of this group in the most feasible manner. The training would consist primarily in acquainting these people with the prime contractor's methods and procedures. A further aim would be to distribute educational material to the subcontractor in the hope that it would expedite the flow of products to the

prime contractor, lower the percentage of rejected work, and, in general, improve the relations between the two companies.

Several methods of approach may be used in handling this problem. The prime contractor may send instructors to the vendor's plant to teach the methods or procedures required to do the job. Supervisory personnel may be brought to the prime contractor's plant for a series of tours and demonstrations. If such plans cannot be applied, the training department of the prime contractor may secure pamphlets or prepare technical papers for distribution to subcontractor's personnel, which will indirectly help such subcontractor to deliver better products.

CUSTOMER INSTRUCTION IN OPERATION AND MAINTENANCE OF EQUIPMENT.—Certain industries must provide training for employees in customer plants so that these workers know how to operate and maintain equipment purchased from manufacturers, e.g., the aircraft industry. Courses of training would be conducted by the sales and service department of the vendor company to teach the customers what they need to know to get satisfactory performance from the product. Such training would begin with the education of a competent corps of service men through whom the training may be carried to the customers. Technical papers and manuals would be prepared as a part of this program dealing with the operating and maintenance problems of the product.

AUXILIARY TRAINING AIDS.—To facilitate the smooth and proper functioning of the entire training program, certain aids and mediums should be provided for both instructor and trainee.

Library Research Service.—While a major portion of plant training is to be conducted in the classroom and on the job, plant library facilities should be provided in which selected books, periodicals, and other data covering the related subjects of the training program are available for any employee's use. The extent of the collection of material in the library will depend largely on the location of the plant and the nature of the company's business. If the company is located in a large metropolitan area, perhaps it will be unnecessary to have an extensive collection. The library can secure the materials needed from other sources in the area on loan as required. It is perhaps more important to have a trained research worker in the library to search material as required, and to act as a clearing house for contact with outside agencies. Such a person can prepare reference data and lists of materials, search for supplementary materials for both instructors and trainees, and help to prepare technical papers used in various phases of the program.

Visual Aids.—It is through the use of such aids as charts, pictures, films, perspective drawings, and slide films that the best results are achieved. Training classes should be supplemented with such visual aids at every opportunity. The use of moving pictures and slide films is now so extensive in vocational education that a film specialist is often a member of the training department. It is his duty to assemble data on films available in both public and private sources. He prepares film programs, and edits films to secure the best results possible. He should also prepare company material for reproduction in slide-film form for use in classes.

Films on vocational subjects have been produced recently on all phases of training. Such public agencies as the U. S. Office of Education, state departments of education, and the U. S. Army and Navy have produced numerous training films, many of which are available to industry. Other excellent slide films are available through commercial distributors. A training department should have, as a working tool, a list of available films, and should use films whenever possible in classes.

Aptitude, Selection, and Performance Tests.—The possible use of standardized tests in a training program should not be overlooked as an auxiliary-training aid. Such tests have been used with great success by numerous companies. They may be applied to eliminate the unfit from training courses, or for guidance when trying to place the right person in the right job. They may be used also to evaluate the results of training.

Although numerous standardized tests are available, they must always be used with caution. There is no basis for the belief that since test "A" was successful in one company, it will be successful in another. Tests will not work miracles for the personnel nor the training department. They must be administered and evaluated by a skilled person. Only when used with caution by a competent person are they an excellent aid to the training, just as is the case with their use in employment.

Instructor and Conference Leader Training.—It should be a function of the training department to select and train members of the company to act as instructors and conference leaders as needed to carry out the training program. Even if a majority of instructors are available through outside agencies, there is always a need for company men to act as instructors, since certain phases of training are best taught by men who know company policies and procedures thoroughly.

There are several plans that may be followed for training instructors and conference leaders. The company may assign men specifically for the job, such as members of the training department staff. The state departments of vocational education are usually equipped to train instructors and conference leaders upon request. Private agencies may also be employed to do this kind of training.

In selecting men for instructor or conference-leader training, the accent should always be on certain fundamental characteristics. A man may know his job thoroughly, but have none of the attributes necessary in a good instructor. By the same token, a conference leader may be a specialist in a particular field and yet lack the judgment and emotional stability of a good conference leader. The success or failure of any training program in a large measure depends upon the personal qualifications of the instructor or leader.

Planning for Safety

IMPORTANCE OF SAFETY TO PRODUCTION.—In one recent year, accidents in industrial plants cost 380,000,000 days lost to production by the 50,000,000 workers employed, or an average of 8 days per worker per year, in addition to all other causes of lost time. The importance of safety training and engineering as a means of accident prevention requires no more forceful demonstration than is given by these

figures. The safety consciousness and will of the employee to aid in preventing accidents rests first and foremost on the management and the executives and supervisors directing production. It is axiomatic, moreover, that: "The safe plant is an efficient plant. The efficient plant is a safe plant."

TEN BASIC STEPS IN PLANNING FOR ACCIDENT PREVENTION.—Top management in any plant must first be convinced of the value of a safety program, and particularly that management must play a continuous, active part in carrying it along. In many cases executives are convinced of the necessity of an organized effort to prevent accidents to workers, but are uncertain of the best methods for conducting such a program. Many plans—some of them far reaching—have been formulated for the prevention of accidents. Regardless of the size of the company and the kind of work in which it is engaged, all these plans are based on fundamental principles which start with ten simple, basic steps that are necessary for starting any program to prevent accidents. These steps are usually undertaken in the following order:

1. **Obtain cooperation of plant manager.** The manager must do his part in helping to "put safety on the map."
2. **Obtain cooperation of superintendent.** The superintendent must make safety an integral part of the operating organization.
3. **Appoint safety director.** One man must be designated to direct the safety program.
4. **Analyze accident records.** After his appointment, the safety director should analyze the accident reports for the past year or two to learn, if possible, the how, who, where, when, and why of each accident.
5. **Hold meeting of operating executives.** All foremen, superintendents, and operating heads should then be summoned to a general meeting presided over by the manager or general superintendent.
6. **Make inspection of operations.** Following this meeting each foreman should make a complete inspection of his department.
7. **Start mechanical safeguarding.** The safeguarding program should then be developed and carried out, making sure that the most serious conditions are corrected first.
8. **Make general announcement.** Then, and not until then, should the workers be acquainted with the accident prevention plan.
9. **Organize educational work.** Formulate a program to maintain interest and supply information on safety to management, foremen, and workers. Consider appointing workers on plant safety committees.
10. **Consider engineering revision.** Consider methods for improving machinery, equipment, and processes to eliminate hazards and increase production efficiency.

LOSSES CAUSED BY ACCIDENTS.—The heavy toll of fatal accidents throughout the United States is further reflected in data issued by the National Safety Council for the year 1942, and summarized in Fig. 13. Nonfatal injuries from 1942 accidents numbered approximately 9,200,000. Accident costs totaled about $5,200,000,000, including wage loss, medical expense, overhead costs of insurance, property damage in motor vehicle accidents and fires, and the so-called indirect costs of occupational accidents. The loss from these accidents to workers amounted to the previously mentioned huge loss of 380,000,000 productive man-days, or 8 days for each of the 50,000,000 workers, in spite of the fact that full-day absences due to work accidents run less than one day per worker

per year, and that off-job accident absences average only a little more than one day.

But, while millions of workers manage to stay on the job after an accident, their efficiency is permanently or sometimes temporarily impaired. Tens of millions of workers must take time to get the necessary first-aid treatment for preventable injuries. These and other direct losses continue to drain away productive effort, particularly under a system of continuous-flow production. An accident may slow up the production of one plant, and delay of that product may prevent an assembly plant from operating at full speed, and so on, until a single accident may have widespread effects.

Kind of Accident	Total Number of Persons Killed
Home	30,000 of which 6,000 were workers
Motor vehicle	28,200 of which 16,500 were workers
Occupational	18,500 of which all were workers
Public (except motor vehicle)	14,000 of which 6,500 were workers

FIG. 13. One Year's Fatal Accidents in the United States

DEVELOPING THE PLAN.—The set-up of a safety organization and program may be further explained by referring back to the ten basic steps but in more detail:

The Manager.—Safety must start at the top. First, the manager must do his part, and his part is to "put safety on the map," make it a necessary part of the process of production, get back of it and keep back of it so actively that every foreman and worker will know what the company proposes to do to help make the plant safe. Any safety organization without an enthusiastic manager back of it is bound to fail. The manager must convince his men by visible signs, in the form of mechanical guards, good lighting, etc., that he is doing his full part, before he can expect his men to take safety seriously or give any genuine cooperation. It is especially important that the manager bring his superintendents and foremen to believe in safety just as they believe in production, and give it their wholehearted and intelligent cooperation. This backing can be brought about by demanding from the organization exactly the same degree of attention to safety as to production, by frequent conferences, and by placing before the foremen the experiences of other companies which have done successful accident prevention work.

The Superintendent.—What applies to the manager applies equally well to the superintendent; he must be the field marshal in the safety campaign, and by his own faith and enthusiasm he must win for it the respect and support of his foremen. If he treats it as a side issue, his foremen will treat it likewise. It must be made a vital part of the operating department. The superintendent should keep in close touch with the safety director and acquaint himself with every important feature of the safety program so he will be able intelligently to discuss and aid in the work.

Safety Director.—One man must be responsible for the safety work in every plant, regardless of its size. In a small plant it may be advisable or necessary for the manager himself to carry this responsibility. In

a medium-sized or large plant, he may delegate this responsibility to an assistant whose duties and qualifications will determine whether he should be known as safety engineer, safety director, safety inspector, or by some other equally significant title. (For the sake of uniformity, he is referred to here as the safety director.) In the medium-sized company he need not devote his entire time to accident prevention, but under no circumstances should this responsibility be given as a sideline to an already overworked individual.

In addition to a knowledge of safety, the successful safety director must have nearly every **personal qualification** that is to be found in successful men in all walks of life. He should have vision, initiative, persistency, judgment, diplomacy, leadership, and, above all, sympathy. To be worthy of the title "engineer" he should have had a technical training or its equivalent in actual experience. Such professional qualification is unquestionably required in large organizations, or where difficult technical problems arise.

An important feature of accident prevention work is that the safety director should know the men he is working for and with, because much of his success will depend upon the manner of his contact and his dealing with the men. The accident prevention work which is most constructive and most lasting is often accomplished by getting other men to do the work. Sometimes this participation is brought about by suggestion, perhaps by a direct request or as a personal favor, and again by an order from the manager or superintendent. Whatever the means, the result will be that the man who does the work is interested to a greater degree than he would be otherwise, and feels a personal responsibility for his share of the work. If handled tactfully, this principle will work with the plant engineering department and the plant executives, as well as with the workers.

The safety director's actual **position in the plant organization** varies with the general organization of the individual plant. In some plants the safety director will have charge of practically all employee relations, including employment, safety, sanitation, health service, general welfare work, employee activities, etc. In any event, the safety director should be in close touch with the department handling the employee relations throughout, so that his work may be definitely coupled with the other branches of work of that department. It is now generally accepted that practically every phase of an employee's life has a bearing on accident prevention, and it is for this reason that, if the safety director has no direct control over the company's relations with its employees, he should be connected with the department handling such relations. The educational side of accident prevention is very definitely an employee relations proposition.

Analysis of Accident Records.—It is assumed in this discussion that no safety work has been attempted in the company other than the safeguarding required by an insurance company or the state factory inspector. In accepting his position the safety director will have satisfied himself that the management is sincere in its desire to prevent accidents and that it proposes to follow every reasonable and practicable plan for securing the cooperation of its employees in safety work. The first step which he should take after his appointment is to start an analysis of the company's accident reports for the past two or more years. While mak-

ing these analyses of accident records, the safety director should take advantage of every opportunity to establish personal and close relations with the superintendent, foremen, and other plant executives. Doing so may prevent unpleasant misunderstandings later on.

Meeting of Operating Executives.—The next step is to call a meeting of all foremen and department heads, at which the works manager, general superintendent, or some other executive of the company should preside. The following things should be accomplished in connection with this meeting:

1. The operating executives, and particularly the foremen who are acknowledged as the lieutenants of industry, should be notified of the accident prevention plan in advance of the workers.
2. The safety director should be officially introduced and his duties outlined.
3. The attitude of the company toward accident prevention should be definitely outlined, emphasizing the willingness of the management to back up the operating executives—by discipline, if necessary.
4. The operating executives should be notified that they will be held responsible for accidents to men under their supervision, and impressed with the fact that the success of the safety effort depends upon their leadership and good example.
5. The benefits of safety work can be proved by giving records of other companies.
6. Each foreman should be asked to prepare a report describing conditions in his department and listing the points of danger which need safeguarding.
7. These men should be acquainted with the past accident experience of the company.
8. The bearing accidents have on labor turnover and production costs should be pointed out.
9. The point should be emphasized that the dollar side of safety means more to the workers than it does to the company, and that the workers suffer all the physical pain resulting from accidents.
10. By referring to past experience, it should be demonstrated that approximately 90% of all accidents are preventable and are the result of ignorance, carelessness, faulty supervision, etc.
11. The safety director (and possibly one from another plant or an insurance company) should acquaint these men with the methods used and results obtained by other companies.

It is the custom in many companies to hold weekly, biweekly, or monthly meetings of foremen and other operating executives to discuss production and operating problems. In such cases a special meeting need not be called. One of the regular meetings can simply be extended 15 minutes or half an hour to carry out the plan suggested above.

Plant Inspection.—Following this meeting a complete inspection of each department should be made. This inspection is made to:

1. Help the foreman in each department prepare his report as requested at the foremen's meeting.
2. Determine the physical condition of the plant and to check all dangers that need to be safeguarded.
3. Prepare for the guarding program.
4. Improve general housekeeping, sanitation, etc.

In making these inspections, the safety director should accompany the foreman of each department, but the inspections should be made, and the reports written, by the foremen—not by the safety director. The safety

director's duty is simply to help, by suggesting ideas to the foreman, by making sure that the most important things are not overlooked, and by encouraging the foreman to correct many of the conditions within his control without referring them to other departments or to persons of higher authority.

The safety director should not worry if the foremen fail to note all of the unsafe conditions that should be corrected. If none of the serious conditions are overlooked, many of the minor items can be "caught" at later dates.

When making an inspection it may help to know just where accidents have occurred in the past. Nevertheless, the inspectors should also ask themselves the question "Can an accident occur here?"

Mechanical Safeguarding.—After all inspection reports are turned in, the safety director should help the superintendent to determine just which recommendations made by the foremen should be carried out and in what order. Many recommendations should be referred back to the foremen from whom they originated with orders to "go ahead." Others may have to be referred to the master mechanic or to some other person or department for necessary action. Other recommendations which seem impracticable or on which favorable action cannot be taken at once, should be discussed either by another meeting of all foremen or with the individual foremen by whom they were submitted.

Carrying out this part of the program satisfactorily will not only eliminate the majority of the accident hazards which are within the control of the management, but it will also impress upon the minds of the workers the fact that the company is sincere in promoting safety and willing to do its full part toward that end.

General Announcement.—After the company has made a definite start in its plan to correct unsafe conditions, then, and not until then, should an effort be made to secure the active cooperation of the workers. The first step in this direction is to acquaint the workers with the fact that the company is starting an organized effort to prevent accidents, that most accidents result from either unsafe conditions or unsafe practices, and that the company will do everything in its power to make dangerous conditions safe. On the other hand, it should be stressed that since the workers are primarily responsible for unsafe practices, they will be expected to do everything in their power to perform their work safely, and to prevent accidents not only to themselves but also to their fellow workers. In addition, the workers should be encouraged to suggest ways and means of preventing accidents.

These facts may be communicated to the workers through personal letters from the management, through announcements posted on the bulletin boards, through the plant publication, at departmental meetings, or at a general mass meeting. Such a step is necessary to give publicity to the plan and to arouse enthusiasm for carrying it out. Without the cooperation of the workers, the plan will fail.

Educational Program.—After the steps outlined in the preceding paragraphs have been taken, the problem becomes one of maintaining the interest and increasing the knowledge of the management, the foremen, and the workers in safety. Such a variety of methods have been created to accomplish these objectives that the safety director must use consider-

able discretion in selecting those methods which can best be adapted to the personalities of the individuals with whom he is working. This step requires unlimited imagination, leadership, ingenuity and persistence.

It is extremely important for the safety director to prepare a sufficient number of brief, concise reports at proper intervals to **keep the management acquainted with the progress** being made. Furthermore, it is highly advisable for the chief executives to attend safety meetings from time to time, not only to encourage others by their presence but also to keep in touch with the routine work. Another certain way to retain the interest of executives is to bring to their attention all of the details of a few important accident cases, describing family and home conditions of the injured workers, thus arousing their sympathy and emphasizing the good that can be accomplished through effective, thoroughgoing accident prevention work.

Foremen and department heads are usually so busy on production and other problems that some special plans are necessary to maintain their interest in, and active support for, accident prevention.

In many companies, safety committees are organized not only to educate the committee members but also to give them certain legislative and executive responsibilities, such as:

1. To determine standards for guarding machinery and equipment.
2. To formulate safety rules.
3. To investigate all accidents and decide what must be done to prevent their recurrence.
4. To review all safety suggestions and recommendations and decide upon their practicability.

The size of the company and nature of its business are usually the determining factors in selecting the personnel of the safety committee. Workers as well as supervisors should be represented on the committee.

Engineering Revision.—Engineering revision means the improvement or redesign of machinery, equipment, and processes so as not merely to cover up hazards but to eliminate them and at the same time increase operating efficiency and quantity of production. This engineering phase of safety is often neglected, but it can well be made a major activity that will pay unusually large returns on all the time and effort that may be invested. Safeguards are usually only temporary expedients awaiting the development of more fundamental means of eliminating accident hazards. For instance, several years ago numerous gates and guards were installed on power presses to sweep away the operator's hand when the ram descended. These safeguards have now become practically obsolete because of the development of mechanical methods of feeding. These feeding devices make it difficult, and in most cases impossible, for the operator to get his hand into the danger zone.

One of the companies that pioneered in engineering revision as applied to power presses has practically eliminated all power press accidents, whereas such accidents formerly cut off an average of 36 fingers a year. Not only that, but the production of these presses has been increased 60%. What has been accomplished in this particular operation can, and should, be accomplished in many other industrial operations, and the safety director is often looked to for leadership in this work that is so fundamental and far reaching in its effect.

Safety Organization and Training

SAFETY ORGANIZATION.—A safety organization may be set up in several ways to suit the size and need of the plant. Some plants prefer a group of representatives composed of foremen who meet together with the safety engineer or safety director weekly, biweekly, or at long intervals. At such meetings a well-defined plan should be followed (which will be discussed later) and accurate records of the proceedings kept. The safety director may act as secretary or chairman, and every member of the group must take an active part through a well-regulated procedure. Robert H. Luckenbach, Safety Director for Edward G. Budd Manufacturing Co., suggests that some of the workers themselves may be selected for this committee to make the program more effective.

Safety Director.—The safety man is the representative of management in accident prevention activities carried on in the plant. The chief operating executive, however, should attend as many safety meetings as possible and take an active part in the entire program. When this practice is not possible, one of his assistants should be delegated to perform this duty.

While responsibility for safety rests largely with foremen some plants have felt that a completely organized department whose members spend 100% of their time on safety work is much more effective. By this method a definite place is found where management can focus responsibility for accident experience. In this case each safety inspector is held responsible for the progress made in his particular area or building. This method, of course, must cover "round the clock" presence of safety inspectors, each thoroughly familiar with the hazards present and the methods of correcting them. The department must have authority granted by the top management to cover such important matters as shutting down dangerous jobs, recommending increased rates of incentives for a safety factor, and designation of the type safety device which must be used. Administration of any necessary discipline is best left to foremen and superintendents. The safety inspectors, in short, must act in an advisory capacity but, for the most part, should have sufficient experience to operate practically any job, or show how it can be done in a safe manner.

Safety Department.—A safety department should have a reasonably central location, near the dispensary if possible, and sufficient office equipment to provide for group meetings. Since outside state and federal inspectors, insurance representatives, salesmen, etc., will have business with the department, a good appearance is essential. Again, employees involved in accidents, or in search of information, should gain confidence in the department through the type of surroundings. A supply of safety magazines, samples of safety equipment (new and damaged by near accidents, etc.), and a blackboard should be handy for demonstration. Files, charts, etc., of course, must, be developed, together with accurate records from which the experience in frequency and severity may be obtained, which will be discussed later.

SAFETY FACTORS AND THE NEW EMPLOYEE.—As far as the worker is concerned, the **best place to start safety work is in the**

employment office. Now that safety has attained a more prominent position in industry, prospective employees often mention, in their early remarks about experience and background, the fact that they have always been safe workers and sometimes display buttons or identification to prove it. It behooves the interviewer, of course, to determine by careful questions whether the prospective employee has safety uppermost in his mind, which is a question somewhat difficult to determine. Casual observation on the part of the interviewer should help somewhat, for example, if he discovers parts of fingers missing or scars or other marks of accident experience. Aptitude tests sometimes disclose clumsiness and haphazard or needless motions, which do have a tendency to make a person accident prone. The value of such tests has been a much-talked-of subject in safety circles of late years, but there is still much room for further analysis.

The new worker, after being hired and having passed the required physical examination (which often discloses additional information of a vital nature which should be picked up and recorded by the safety department), should find, through the information given him by the employment department, that safety is an integral part of his work, beginning the very day he starts. Many companies use safety booklets, or a standard plant publication explaining various procedures necessary for the new employee in which a generous amount of safety advice should be included. In addition, waiting rooms often have racks containing publications on safety, and posters in conspicuous places are excellent reminders of the value of safety. Such mediums give the new employee his first impression of the company and it should therefore be one of confidence, safety, and an invitation to produce good work for good pay and under inviting surroundings.

A valuable method of **follow-up after a worker is hired** is an informal talk by a member of the employment division, say a counselor. All the vital information which a new worker should have can then be supplied perhaps to the new employees in a body, at which time safety can be made more real to them by actual safety devices such as goggles, shields, caps, tools, etc., displayed in a suitable place in the room where these items may be inspected and explained. Tools and devices damaged by accidents in which workers were injured impress upon new employees that safety precautions are highly important.

It should not be supposed that office employees and others who have at least some contact with the shop are immune from accident. Many office workers visit the shop, and at times even try their hands at operating machines or talk with those engaged in dangerous work. Women with their high heels, open toe and heel shoes, loose hair, etc., do not realize their danger when exposed to shop conditions. Office people, therefore, should be warned of the dangers in the shop.

The training director, the counselor, or their assistants often take new employees to their foremen. The new workers are thus placed more at ease and gain confidence. The counselor can show them the department facilities—washrooms, drinking fountains, lunchrooms, and the like. Every such means for making a worker feel at home in his new environment will contribute to his safety. He should then be introduced to his new foreman.

Maintaining Interest in Safety

KEEPING THE SAFETY PROGRAM ACTIVE.—There are many ways in which the safety movement may be kept actively before employees. Posters, bulletin boards, banners, etc., are of definite value, but they are not new devices and their use must be carefully controlled to keep them effective. Action posters describing current events, together with a safety message in the same area of display, bring about a keen interest in both, but they must be changed frequently or they will be passed by unnoticed. Pictures of well-known workers who have accident-free records or devices which have saved employees from injury should be displayed on well-lighted and conspicuous bulletin boards.

Congratulatory messages from management when an excellent safety record has been accomplished will never go unnoticed by workmen. Personal letters mailed to new employees stressing the value of safety are often an important aid to training. These letters should preferably originate in the executive office, so that workers will be made to feel that the "big boss" is vitally interested in the safety and welfare of his employees.

Plant publications and house organs can perform an important service in selling safety to readers. Photographs of well-known "buddies" together with their remarks about safety, particularly if they have been personally involved in accidents, attract much attention. Publication, through this medium, of records of progress in safety in various departments, together with suitable remarks from company officials, bring about a spirit of cooperation. Since most of these publications find their way into the homes, the messages may be read and reemphasized many times.

Awards and Exhibits.—A company in Philadelphia having an excellent safety record used a novel method of maintaining interest in its safety program. Once a month, a **prize drawing** was made in each department where no lost-time accidents had occurred. Each employee placed a check stub, upon which his shop number appeared, in a box during the week when such a drawing was to be made. At a specified time, usually at the close of one shift and the beginning of the next, workers assembled in their own departments. The safety engineer, in each case, picked at random one of the group who drew the numbers. The prize was a radio, and great enthusiasm was demonstrated in each of these drawings. After a department had worked for 6 months without a lost-time accident, a special prize drawing was held, at which time a higher priced radio was given, or another article of corresponding value. **Grand prizes** were given at the end of a year. Keen competition in accident prevention developed out of this plan. Other systems of publicity have been used, including large charts portraying horse-races, airplane engagements, thermometers, etc., to keep up a continued spirit of healthy accident-prevention work.

Cash awards, medals, etc., are sometimes given for valuable safety suggestions, good safety records, and outstanding work done by individual employees. Many valuable ideas for progress in safety, and in production as well, have resulted from these suggestion systems.

An effective way of obtaining the interest and cooperation of employees is to make a **well-prepared exhibit** of tools, goggles, safety shoes, etc., which have actually been damaged in service as protective devices. A smashed pair of safety pliers, broken goggles, damaged safety shoes, are always helpful in cases where those who must be "shown" are concerned. Each article definitely becomes an object lesson to employees, many of whom may have rebelled when requested to use such protective devices. While it is not good psychologically to lean too far toward the gruesome side of the instruction, effective results have been obtained by such expedients as, in one case, carrying around a generous handful of hair torn from a girl's head by a machine accident. Together with the fact that a generous part of the root end of the hair was black while the balance was of a decidedly blonde hue, the effect was particularly good in deciding for a few doubting feminine machine operators that a safety cap should be worn at all times by women doing shop work.

Classes for Instruction.—There are courses in safety engineering, and for training industrial supervisors in safety, which are well worth the time and attention of foremen, leaders, and safety inspectors, to assist in building up a strong organization to attack accident problems. With such basic training, a well-defined program can be set up to fit the various individual needs. When a well-regulated program has been designed to fit in with the safety department or safety director's plans, a high degree of cooperation with all departments should result.

Meetings.—Management will find more and more that meetings involving plant matters in general should include the safety director. Committees considering new methods, the use of new materials, production set-ups, purchase of new machinery, and other problems should realize that nearly every phase of their proposed plans has items which require the consideration of safety. Factory layout departments considering the setting up of new manufacturing facilities or the relayout of present floor areas need to consider the hazards in storage of material, handling and storage of work in process, plant transportation, materials on the floor in traffic aisles, dangerous turns in aisles, and many other details which sometimes are planned without thought of safety. Die and tool design may bring about many hazards which do not always show up on the drawing board, and a safety director who is continually looking for such hazards can many times suggest changes for clearance areas in dies, the use of dial feeds, chutes, and automatic feeds which not only produce a safer tool to work with but also permit in most instances an increase in production. A slightly high first cost which reduces costly accidents and increases production is certainly money well spent.

SAFETY FACTORS IN TRAINING WORKERS.—Through the careful analysis of jobs from the safety standpoint, plans can be developed whereby workers can be instructed to do their jobs in the safe way. Besides the foreman's verbal and manual training, other methods may be used. On production cards, tally sheets, or time cards for jobs, a short, concise safety message may be included. For example, on a press job where there is a definite hazard of operation, there may be written or printed on the card, "Job must not run unless guard is in place," or, "Use safety pliers on this job," or, "This job must not turn over, it is

rated for start and stop." On portable tools such as grinders, either air or electric, name plates should be fastened to the machine indicating such information as, "Do not use wheel larger than four inches diameter," or, "Goggles must be worn while using this tool." Again, where automatic-push-button control devices are used for series operation, a sign should read, "All buttons must be open while working this job unless otherwise authorized by your foreman." A collection of safety information placed directly in front of the worker at the time he is to use the device is more effective than a book of rules, or a previous warning on the bulletin board or verbally by the foreman.

The promotion of such safe practices throughout the entire organization develops safe thinking for future accident prevention. The use of red danger tags on machines shut down for the correction of some accident hazard has proved valuable in many instances. To place a tag such as Fig. 14, reading "Danger, do not use," on any device or machine arouses inquisitiveness among the employees, and even the foremen from other departments, who usually stop to look at the tag to discover why the machine or device is not in operation. The plan also has a much-desired effect on the production departments, which urge the repair division to get the machine back into service. Since the machine has originally been shut down by the safety department, the advertising feature is obvious.

Date NOV 2 19__ Time 10 AM No. 460

This equipment has been ordered out of service by the Safety Dept. for the following reasons BAD CORD AND PLUG

Signed [signature] Safety Dept.

DO NOT USE

I hereby vouch that above condition was corrected before equipment was returned to service.

Date Ret. to Serv. 11/9 19__ Signed [signature] Mech. Dept.

Date NOV 2 19__ No. 460

Time 10 A.M.

Dept. 2R Notified ELECT.

Equipment PORT. GRINDER

Location 2R

Reason for Tag BAD CORD AND PLUG

Signed [signature]

DO NOT FILL IN: Ret. to Serv. 11/9 19__; No. of Days Lost 7

FIG. 14. Warning Tag (red) Attached to Equipment Ordered Out of Service

SAFETY RULES.—To set up a standard group of safety rules for plant practice is obviously a difficult matter in consideration of the wideness of the field of industry but it can be done if suitable information is obtained (Safe Practices Pamphlets 80 and 93, National Safety Council). Rules established by companies engaged in similar work may be studied to good advantage. This valuable exchange of safety ideas and contacts made through local and the national organizations, together with the data made available by casualty insurance companies and state labor departments, will be found to be a continued source of vital and up-to-date information.

Safety rules cannot bring about a reduction in accidents unless provision is made for **enforcement.** Enforcement, however, is not entirely a matter of discipline. One of the first steps toward rule observance is that all supervisors must become familiar with the rules and follow them continually. Their good example can do much to influence the workers.

If they disregard the requirements, the workers will feel privileged to do likewise. The best weapon of enforcement is patience and perseverance rather than threats, insults, and discharge slips. Some few workers, however, will resist even the best efforts of the foremen and safety advisers, and stern warnings should be given for such deliberate violations. If after a short lay-off for a wilful violation of an important rule, the worker persists in such disobedience of safety rules, a long lay-off or discharge is in most cases required. When labor groups or unions represent employees, these groups should be consulted and an agreement made upon methods of enforcement to be used when the occasion arises. Continual offenders always become involved in accidents if given sufficient time.

Engineering Factors in Safety

MECHANICAL.—Only in comparatively recent years have machine-tool builders included adequate provisions for safety in their design. Proper guarding before that time, for the most part, was left to the customer, since lack of uniformity in state regulations often meant special guards to meet the respective requirements. The user, however, in every case must carefully check each item, from the mechanical transmission of power to the machine up to the point of operation, on through each step in the process to the delivery of a finished or partly finished part. Mechanical power transmission apparatus includes all shafting, belting, pulleys, gears, starting and stopping devices, and other moving parts of such machinery. Reliable starting and stopping equipment must be provided for the safe and efficient operation of power transmission apparatus. These devices together with their auxiliaries include: belt shifters, belt shippers, poles and perches, clutches, and remote control apparatus. The American Standards Association has many approved safety codes covering equipment.

Belts have caused many accidents. Attention cannot be called too forcefully to precautions which should be taken in maintaining and safeguarding them. The grade of leather, rubber, fabric, or composition used is important. Conditions surrounding the use of the belts, such as dampness, exposure to steam, heat, cold, grit, etc., have considerable bearing upon belt efficiency as well as the safety of those who work near moving belts. Factors of strength, working loads, tension, speed, splicing and lacing, must all be considered, and complete enclosures for belts should be provided wherever possible. The construction of the belt guard must be carefully considered, using expanded metal, perforated or solid sheet metal, or wire mesh on a frame of angle iron secured to the floor or the frame of the machine. Suitable access doors or hinged sections should be provided so as to make complete removal of guard unnecessary, when adjustments to the belt, etc., are required. Many guards, because of their impractical construction, are left off entirely by employees.

Mechanical guarding of **shaft couplings, collars, keys, set-screws, pulleys, gears and sprockets, and chains** will do much to prevent injury to workers. The same care should be used in making guards for such moving elements as is taken for belts and any other moving parts. Standard practices should be set up calling for the use of revolving col-

lars of the cylindrical type, without projecting screws and bolts, and set-screws set flush with or countersunk beneath the surface of the metal part in which they are inserted. Pulleys, gears, sprockets, and chains which are 6 feet or less from the floor or working platform, or are exposed to contact, should be guarded, and the guards should provide complete safety in case chains, etc., should break while in motion. When frequent oiling is necessary, small openings with hinged or sliding self-closing covers should be provided or oil pipes extended outside of guards. The more intricate guarding of the machine tool itself, or of processing equipment such as emery wheels, belt sanders, power presses, conveyors, portable power tools, etc., should be considered separately and more intensively, since it becomes the hazard usually nearest to the operator.

Hydraulic equipment which depends on high pressures for power must necessarily receive careful study when designed, and piping, cylinders, and other devices should have an adequate factor of safety to protect the operators and any others near such equipment. Even small units, where processing operations require hole punchers, riveters, jig clamps, etc., should have guards over the operating cylinders and other vital parts, since a small blowout will emit a fine stream of liquid at such a high pressure as to do considerable damage if it strikes the human body.

ELECTRICAL.—Generators, power lines, wiring, transformers, etc., should be constructed and installed with the highest standard of safety. All manufacturers of such apparatus recognize this important factor, and the installation and maintenance of such equipment should follow the rules and codes set up by electrical engineering or standards associations. The **smaller tools and electrical devices,** portable drills, grinders, welding transformers, heating devices, etc., because of the large amount of handling they receive, cause many accidents. A constant check of such equipment by competent electricians should be a strictly enforced requirement. Electric shocks of as low as 110 volts, caused by faulty wiring, careless handling, incomplete repair, etc., may sometimes cause serious or fatal accidents. Workers must be taught to take proper precautions with low voltage as well as high voltage, because of the increasing use of portable electrical tools.

Common **outlet boxes and panels** seen in most factories do not seem to be much of a hazard until, by careful check, it is often found that workmen use these places as receptacles for lunches, tools, etc. A short circuit from such a source may result in bad burns and possibly more severe consequences if the eyes are involved. Here again is an opportunity for the safety department to discover hazards and, through the proper departments, eliminate them.

CHEMICAL.—Acids, caustics, and alkalis are used in many industries. Because their use is frequently incidental to other operations, many employers and workers give little consideration to the dangers involved. Acids and caustics in concentrated form, and sometimes even in milder forms, may cause injury in four different ways:

1. Burning, from direct contact with skin or eyes, or indirectly through clothing.
2. Fume poisoning or suffocation. Some chemical fumes are poisonous if inhaled, while others tend to exclude oxygen. If they are in suffi-

cient concentration in the atmosphere, this atmosphere may fail to sustain life.
3. Poisoning when taken internally.
4. Fires or explosions resulting from their improper handling and storage.

Proper protective clothing and devices—rubber and neoprene gloves, boots, wooden clogs, rubber aprons, tight-fitting goggles preferably with rubber face pads, face shields, and acid-proof hoods—are essential.

Chemical burns caused by workers' tripping or slipping while handling containers may often be avoided if floors are kept in good repair and free from grease or oil. Good lighting is also an aid against such accidents. High-grade respirators, of a proper type furnished to suit the kind of hazard to which the worker is exposed, must be available for protection against fumes. A very high standard of safety instruction is required in all chemical plants where large assortments of chemicals are used, and a rigid system of orderliness, both on the part of the worker and of the plant, is essential to reduce the frequency of accidents from this dangerous source. Many chemicals give rise to dermatitis, especially if the employee is allergic to the substances.

MATERIALS HANDLING.—Handling materials causes a large percentage of the compensable accidents in industry. Many companies have found it advantageous to study the work of handling materials by hand as thoroughly as time studies are taken on other operations.

In **handling material by hand,** sometimes a slight change from the usual method of grasping a piece, carrying it, and setting it down will bring about greater safety as well as greater efficiency. Many workers are injured because they do not know the safe method of lifting. Back strains and hernia are likely to develop if workers bend at the waist when leaning over to pick up a heavy or oddly shaped object. Hand protection, such as hand leathers and gloves that will resist rough usage, will often reduce injuries from rough or sharp materials. The large variety of "home-made" devices or specially designed tools have added much to improve handling methods as well as to eliminate accidents. Tote boxes, hand trucks to carry gas cylinders, adjustable die trucks for diesetters, hand trucks for handling sacks, barrels, boxes, etc., and many other devices are supplied primarily to assist workers to accomplish their tasks safely and without strain and fatigue.

Overhead traveling cranes involve too many hazards to be fully discussed here, but precautions to observe on the operating floor below the cranes merit attention, such as avoiding overhanging loads, and observing the warnings of the crane operator and the floor men, who should be trained in safe practices. Complete periodic inspection of cranes and hoists should be rigidly enforced. Special safety meetings should be held for crane men and truck and tractor operators.

Hoisting apparatus purchased from a reputable maker, including devices such as block and falls, chain hoists, air hoists, jib cranes, portable floor cranes, crabs and winches, etc., is usually designed with safety in mind. All these devices are as safe as the operator who handles them, and men with rigging and handling experience should always operate such equipment. These employees should be taught the safe limits of the apparatus, because there is a general tendency to overload such equipment on account of its flexibility in difficult places.

Conveyors involve serious hazards unless proper precautions are observed. No adjustments or repairs of any kind, including oiling, should be made while a conveyor is in motion, unless in the latter case the oiler does not come within dangerous proximity to moving parts. Many accidents have been caused by starting conveyors without first giving warning to men who might be making repairs or adjustment, or oiling the machinery. A lock or warning sign should be provided for repair men to block the control until everyone is clear. Control devices should be installed at frequent intervals in all power-driven conveyors, for stoping the conveyor in case of an accident or other emergency. A safe-footing rubber matting or other anti-slip floor surface should be provided at the loading and discharging stations, and any material which might be spilled from conveyors should be immediately removed. The speed should be such that a worker will have ample time to place material in position without losing his balance, and material being moved should not project over the side of the conveyor or be likely to fall. There are many types of conveyors used: gravity, chute, roller, belt, chain, etc., all of which must be carefully studied when installed to provide the proper safety for workers and for those passing by. Bridges should be provided where it is necessary to cross over conveyors, and overhead conveyors should have inclines to take them up over aisles or passageways to clear any traffic beneath. Guard rails, toe-boards at floor openings, and complete housing of the power drives are likewise necessary. Since the conveyor is a moving device and usually in the open, near workers, every precaution must be taken to insure its safe operation.

Electric or gasoline-driven trucks and tractors, because they traverse or cross aisles, passageways, roadways, elevator approaches, etc., at many points in a plant, present particular accident hazards. Floors must be kept in good condition and aisles must be properly marked off and kept free of materials to prevent injury to truck drivers and to employees working beside the aisles. Operators of trucks and tractors must be taught not to exceed a stated safe speed limit. Entrances to tunnels, crossovers, sharp turns and corners should be clearly marked with warning signs, and warning gongs or horns should be sounded by the operator at such places. The truck itself, of course, should be kept in good mechanical condition, brakes checked, switching devices, etc., maintained in proper repair, and a suitable and very substantial guard provided on the operator's platform to protect his legs. The truck must be considered from most angles practically as an automobile, and the condition of the truck, the responsibility of the operator, and existing traffic conditions are comparable with highway transportation requirements except for the need for a higher degree of safety consciousness incident to the very close manipulation required in the plant.

GRINDING, BUFFING, AND POLISHING.—Grinding wheel is a term often used in referring to all rotating devices used for grinding or polishing. **Abrasive wheels** are solid wheels made of abrasive particles held together by natural mineral or artificial bonds. **Grindstones** are flat circular stones made from natural sandstone, the cutting material of which is oxide of silicon, or quartz, as it is commonly called. **Polishing and buffing wheels** are sometimes made of wood and faced with paper or leather to which emery or some other suitable abrasive is glued, or

are wheels made of canvas, sheepskin, felt, or paper with a polishing medium of rouge, tripoli, crocus, etc.

Special instructions or regulations covering the use of such wheels have been formulated by, and are available from, grinding-wheel manufacturers, state labor departments, the National Safety Council, and other sources. In general, all surrounding conditions should be carefully studied to make the use of such equipment safe. Operators should always wear suitable goggles and shields to protect their eyes. Dust generated from dry abrasives is a health hazard and should be removed at the point of origin by an efficient exhaust system.

Whenever a wheel breaks, a careful check should be made to determine the cause of the break. Inspection should also be made to make sure that the hood has not been damaged or the spindle and flanges sprung out of true or out of balance.

Work should not be forced against a cold wheel, but applied gradually, giving the wheel an opportunity to warm and thereby minimizing the danger of breakage. This precaution applies to starting work in the morning in cold rooms and to new wheels which have been stored in a cold place. Great care should be taken to avoid striking the wheel a side blow, such as when grinding castings suspended on chain blocks. Grinding on the flat sides of straight wheels is often hazardous and should not be allowed when the sides of the wheel are appreciably worn or when any considerable or sudden pressure is brought to bear against the sides.

Competent men, only, should mount, inspect, and care for grinding wheels and, preferably, special men should be assigned to do all of this work.

EXHAUST SYSTEMS.—Dusts, gases, vapors, and fumes generated by industrial equipment and processes constitute special classes of hazards:

1. Some dusts have a mechanical or irritating action affecting the parts of the body which may be directly exposed. For instance, sharp-pointed particles of metal or rock may harm the eyes, nose, throat, and skin. If inhaled into the lungs, some dusts may cause fibrosis or chronic inflammation.
2. Corrosive dusts from such substances as soda, lime, and others cause inflammation of the skin or membranes.
3. Poisonous dusts such as lead, arsenic, or mercury may cause general poisoning upon entering the body, or they may attack certain parts of the body, such as blood, bones, or nerves.
4. Dusts from fur, feathers, and hair may carry disease germs which may infect the worker.
5. Irritating fumes from substances such as ammonia or acids act locally upon the eyes and upon the mucous membranes of the nose, throat, and lungs.
6. Poisonous fumes from benzol, wood alcohol, aniline, lead, and other substances often affect the blood, heart, eyes, or nerves.

Dusts, gases, vapors, and fumes are the direct or indirect cause of many of the so-called "occupational diseases" and they can be removed or rendered harmless by employing such methods as the following:

1. Mechanical exhaust system.
2. Installing automatic or closed machinery.
3. Using wet processes.

4. Natural ventilation.
5. Isolating the process or machine that creates dust, gas, vapors, or fumes in a separate room or building.
6. Providing and requiring exposed workers to wear respiratory protective equipment.

HAND TOOLS.—Statistics show that hand tools cause a large portion of the injuries in industry. Mishandling hand tools, neglecting to keep them in proper condition, and leaving them in dangerous places are frequent causes of accidents. It is of prime importance, in the effort to prevent accidents, cut tool costs, and maintain a high rate of production, that only the best materials be used for making hand tools. Chisels, punches, drifts, etc., made from poor stock soon become dull, and their heads mushroomed and cracked. Hence, only tools made from the most suitable grades of tool steel should be employed, not necessarily the special expensive brands of alloy steels, but proper grades for the various purposes. Probably the greatest contribution to the reduction of accidents from hand tools is proper maintenance. Tools with cracked handles, mushroomed heads, improper tempering, etc., should be promptly removed from service and repaired, as a start in eliminating accidents from such sources.

WOODWORKING MACHINERY.—The variety of operations performed on woodworking machines, the high speed and sharpness of the cutting tools, and the comparatively light weight of the wood being worked on combine to produce high accident rates on such equipment. The range of uses of certain woodworking machines makes satisfactory guarding particularly difficult and increases the temptation of workers to operate without guards. The natural course, particularly where the volume of work is not large, is to save in first cost of equipment by performing many different operations on one machine. Actually, frequent changes in machine set-up are so costly in wasted time and in poor work that true economy usually lies in **providing enough machines to limit the operations on each to closely similar work.** It is possible, for instance, to avoid grooving (dadoing) on circular saws or to avoid using two tools that are operated by the same control, as an auger and a grinder on the same spindle. An absolute fundamental for safety in all such combinations is to arrange the drive so that only one tool can be operated at a time.

The high speed at which woodworking machines are operated often causes excessive vibration unless the machines are properly designed and well made, and unless bearings are properly maintained and tools correctly set.

It is important to **enclose completely all belts, pulleys, clutches, gears, sprockets, spindles, and reciprocating parts,** and to provide practical (and, where possible, automatic) safeguards for the point of operation of all woodworking machines. No class of machines, with the possible exception of power presses, presents such difficult safeguarding problems. There are many protective devices on the market for use on various woodworking machines, each of which, however, has certain limitations. Careful study should be given to all operations performed on every machine, and a type of guard selected or made that will be practical and effective for each. It is best to secure the cooperation of the operator and his foreman, for not only does a good operator "know

his machine," but once he and his supervisor put their minds to it, they are likely to contribute just the ideas needed. Homemade guards, if well designed and well constructed, are satisfactory, but if the chief objective is to get something cheap, they are likely to prove unduly expensive in the long run through failure to prevent accidents. A guard that gives a false sense of security may actually be worse than no guard at all.

Machines can best be guarded by the manufacturer. In the purchase of new machinery, specifications should call for guards on all driving parts, as well as for the point of operation. Guards should perform specific functions or meet definite requirements.

WELDING.—The nature of the safety measures to provide for welding depends upon the kind of welding equipment used, whether gas or electric.

Gas welding and cutting include the use of oxygen acetylene, oxygen hydrogen, and other combinations of oxygen with some suitable fuel gas. Acetylene with oxygen gives a much higher temperature than the other combustible gases and for this reason it is generally employed for gas welding. There are many hazards present in the manufacture and use of acetylene, and extreme care must be exercised at all times. Many accidents have occurred by using home made generators. Instead, such equipment should be procured from reliable makers who furnish instructions for safe operation, which should be posted where they will be seen and rigidly followed.

Most of the gas used for welding and cutting is purchased in **cylinders**. These cylinders should be manufactured and filled in accordance with I.C.C. specifications and regulations, and should be properly marked. They should never be handled with a magnet, and a suitable cradle should be provided if they are moved by crane. Careful handling at all times is essential. Knocks, falls, and rough handling are likedly to damage the cylinder, valves, or fuse plugs and cause leakage. Acetylene cylinders should be set on end for several hours before use, to give free vapor opportunity to collect at the top. Oxygen cylinders should have the same careful handling, and no grease or oil should be used on any of the fittings. Oil or grease in the presence of oxygen under pressure may ignite violently and cause serious accidents.

Regulators, gages, hose and hose connections, and torches should be kept in perfect condition at all times and rigid inspection enforced for their careful handling. Suitable clothing and particularly adequate eye protection is essential for welders, and the proper shade of lenses for goggles and hoods will afford ample protection from the light rays. Such equipment should be of a first-class type, even if the cost is much higher. Aprons, shoes, gloves, etc., are required for complete protection. It is important that the operators of such equipment should be fully qualified by adequate training together with all safety precautions to avoid accidents from this type of welding (Safe Practice for Installation and Operation of Oxy-Acetylene Welding and Cutting Equipment, International Acetylene Assn.).

Arc welding is a fusion welding process in which the welding heat is obtained from an electric arc formed between an electrode and the base metal, the heat of the arc being approximately 7,000° F. The welding voltage in most cases is low, but it can become a serious hazard, particu-

larly in locations which are damp and wet. The usual precautions should be taken against coming in contact with live conductors, by use of insulated equipment and personal protective equipment. Where welding current is used for arc welding, and the operator is required to work in a metal enclosed space, **protective relays** should be installed on the circuit so that the operator will not be exposed to an open-circuit voltage of more than 50 volts.

The fact that low voltages are employed should not cause negligence on the part of the operator. Fatal injuries have occurred when persons contacted the frames of welding machines energized by short circuits. Frames of all portable electric welding machines operated from electric power circuits should be effectively grounded.

The electric arc produces **high intensity of ultra-violet and infra-red rays** which have a harmful effect on the eyes and skin under continued and repeated exposure. The effect of exposure of the skin to the direct rays of the electric arc is very similar to sunburn. It may be very uncomfortable and even painful but causes no permanent injury. Ultra-violet rays do not usually cause permanent injury to the eyes unless by continued and repeated exposure, but temporary effects may be quite painful. Even short exposures have caused painful results and disability. Infra-red rays are the heat rays of the spectrum. They do not cause permanent injury to the eyes except from excessive exposure.

It is necessary, therefore, to provide full protection at all times in the presence of the arc, both while the operator is engaged in actual welding and while he is observing welding operations. Both the operator and his assistant must use a handshield or helmet which protects the skin of the face and neck, and which is also equipped with a suitable filter glass (shades 6 to 14) that will provide adequate eye protection. In the selection of filter glass, it is necessary to depend upon laboratory tests as the transmission of ultra-violet and infra-red radiation cannot be determined by visual inspection. Depth of color does not necessarily indicate removal of the invisible radiation which may be injurious to the eyes. Reliable dealers are able to supply filter glasses which have been shown by tests to conform to requirements of the American Standard Safety Code for the Protection of Heads, Eyes, and Respiratory Organs of Industrial Workers.

During arc-welding operations, certain **gases, fumes, and dusts** are evolved by the heat of the arc, depending on the type of welding rods used, the base metal being welded, and whether or not the base metal is coated with such material as oil, tar, salt, paint, lead, zinc, etc. Some of the gases are believed to include oxide of nitrogen, ozone, carbon dioxide, carbon monoxide, sulphur dioxide, and phosgene. Some of the metallic and mineral substances that may be found in the fumes and dust include iron, zinc, lead, copper, manganese, selenium, silica, arsenic, titanium, and fluorine. Poisoning due to the presence of some of these substances in the fumes has been reported, although evidence based on actual cases is rare.

One of the principal health hazards presented by electric welding is **lead poisoning**. If painted or lead-coated materials are cut or welded, the lead volatilizes and may be breathed, causing lead poisoning. Also, "zinc chills" may result from breathing fumes when welding zinc, brass, bronze, or galvanized metal.

It is difficult to obtain definite data concerning the effects of various gases, fumes, and dusts generated in electric welding operations; consequently, it is usually necessary to make sure that employees do not breath them. Where welding is carried on outdoors, or in large, well-ventilated shops, and nontoxic materials are involved, experience shows that welding operators suffer no harmful effects. But in other cases the hazard must be minimized by providing **efficient ventilation and exhaust systems**. Where harmful concentrations of gases, fumes, and dusts are generated, it is preferable to provide local exhaust systems to remove such substances at their point of origin, particularly where welding is done in confined areas such as small rooms, welding booths, tanks, boilers, etc. In many cases where welding operations are permanently located, the entire booth may be ventilated by an exhaust system such as is used for spray coating booths, or an adequate exhaust pipe may be provided, connected to a central duct system. Portable exhaust systems are also available for this purpose.

Where, because of the intermittent nature of the work or for other good reasons, it is impossible for gases, fumes, and dusts to be kept below their toxic limits by means of general ventilation or by local exhaust systems, welding operators should be required to wear **special respiratory protective equipment** approved for such purposes by the United States Bureau of Mines. Supplied-air respirators, such as air-line respirators, hose masks with or without blowers, or self-contained oxygen-breathing apparatus, are recommended for use in confined areas and other locations where high concentrations of toxic substances are encountered.

The present safe practice is to **ventilate all welding operations** which are carried on in relatively small enclosed or restricted spaces, such as in tanks, boilers, pressure vessels, compartments and holds of vessels, etc., because of the possibility of an accumulation of toxic and explosive gases, and the possibility of an oxygen deficiency. Where there is any question, tests should be made to determine the presence of toxic and explosive gases, and, if such gases are found in harmful concentrations, the area should be thoroughly cleaned and ventilated and again tested before permitting welders to enter. Artifiicial ventilation may be necessary. Tests for oxygen deficiency should be made. Safety lamps and other instruments are available for this purpose.

Resistance welding is a metal-fabricating process in which the fusion temperature is generated at the joint by the resistance to the flow of electric current. When the welding temperature has been reached, the electric circuit is opened and mechanical pressure is applied to complete the weld. The three fundamental factors of resistance welding, therefore, are current, time, and pressure, each of which must be accurately controlled.

The principal **hazards in the operation of resistance welding** equipment include lack of point of operation guards, flying hot metallic particles, handling materials, unauthorized adjustments and repairs, and possible electrical shock. The hazards involved vary greatly with the type of equipment being used and the kind of work being performed. It is suggested that a careful job analysis be made of the operations on each welding machine to determine the safeguards and personal protective equipment that will be most appropriate for each job.

On many kinds of resistance welders, particularly automatic and semi-automatic equipment, serious **point-of-operation hazards** exist similar

to point-of-operation hazards on punch and forming presses. The possibility of finger amputation requires the installation of guards or devices that will enclose the point of operation or otherwise make it impossible for the operator to reach into the danger zone. In most cases welding machine operators should use some form of face and eye protection to guard against flying hot metallic particles. Goggles with clear lenses and sideshields provide effective protection for most resistance welding; however, goggles with filter lenses (shades 1 to 5) may be necessary on some special operations. Face shields to protect the face and neck from hot sparks are desirable and should preferably be of fire-resistant material.

The hazard of **flying sparks** can also be eliminated by installing a shield guard at the point of operation. Such guards should preferably be of transparent material such as safety glass or cellulose acetate. Where such guards are not used, it is good practice to erect some type of shield to prevent injury to other employees who may be passing the machine.

On many operations, leather or canvas gloves and aprons are desirable for preventing burns from hot sparks and in avoiding cuts and scratches. In addition, some operators wear leather sleeves primarily to avoid burning their clothing and also to guard against small skin burns. Woolen outer clothing is preferable to cotton as protection against burns.

FIRE AND PANIC.—Practically every fire can be extinguished within the first few minutes if proper equipment is brought into service by men who are trained in its use. Successful extinguishing of fires generally does not require elaborate, expensive equipment; the essentials are the **right kind of equipment** suited to the existing hazards, kept in good condition, in the right place, with men trained to use this equipment and to bring it into service immediately after the fire is discovered.

The evident reason for extinguishing fires promptly is to prevent their spread and the resulting property loss, but protection of life is of much more vital importance. Even in well-constructed buildings, with ample exits, a fire which is allowed to spread may cause panic and injury if not loss of life. In buildings of inferior construction, with substandard exits, the safety of the occupants demands the most careful attention to fire-extinguishing facilities as well as to fire alarms and drills and to fire prevention.

Every industrial plant, regardless of its type or size, needs some kind of private **fire-fighting organization.** Small plants located in well-protected areas, and with few or no unusual fire hazards, may not require an elaborately organized fire brigade. Larger plants, often situated in isolated areas, and with a variety of fire hazards, generally maintain extensive private fire-protective systems.

Plant operators and those entrusted with the safety of their employees must seriously consider various problems when planning **emergency evacuation of buildings.** Panic in many cases has caused more loss of life than the fire; every effort should be taken to prevent it. Fire is still the primary cause of panic, but boiler or air-tank explosions, chemical explosions, skylight collapse, or structural failure may require prompt and speedy use of emergency exits to avoid panic or loss of life. None of these possibilities can be ignored in preparing an emergency exit plan. No plans or physical alterations should be made which prevent safe evacuation under *any* circumstances that might arise.

Smooth, safe functioning of an exit plan requires a thorough knowledge of all plant operations and kinds of employees, number and type of exits available, width of exits, proper location of exits, possible alternate exits, degree and location of hazard, as well as a knowledge of warning and evacuation facilities.

ENGINEERING DESIGN AND LAYOUT FOR SAFETY.—L. P. Alford, in Principles of Industrial Management, states:

Engineering design of safe machinery and equipment, and safe conditions of production and maintenance, will do much to eliminate or obviate the mechanical, electrical, chemical, and fire hazards. The following requirements which should be given consideration are adapted from De Blois (Industrial Safety Organization):

1. Provide ample space around individual machines or process units for normal operation, adjustments, usual repairs, and materials in process and finished work.
2. Arrange machines and units in a logical sequence to give a direct flow of material, with a minimum of intersecting aisles.
3. Select machines and units of correlated capacity so that there will be a minimum of banking of materials in process and finished work.
4. Install a sufficient number of units to permit necessary time for ordinary adjustments and repairs, without curtailing production as a whole.
5. Provide efficient, safe, and flexible facilities for moving materials in process and removing finished work.
6. Provide ample and convenient facilities for packing and stowing materials, parts, and finished goods.
7. Provide ample and direct approaches, aisles, stairs, and other thoroughfares, free from obstruction.
8. Select central locations for elevators, tool cribs, washrooms, emergency rooms, and toilets.
9. Provide exits ample to evacuate the working force rapidly in case of fire.
10. Provide a power system with minimum potential energy exposure, and minimum mass and individual exposure to human contact.
11. Provide means for the safe and quick cut-off of mechanical power, electric current, steam, gas, and liquids, not only at the individual machines or units, but also from rooms and buildings.
12. Provide heat, ventilation, air conditioning, and facilities for the removal of dust, fumes, steam, and vapors.
13. Provide adequate natural and artificial lighting wherever employees work, pass, or congregate.
14. Provide for proper housekeeping.
15. Provide for the safe routing of outside traffic, both pedestrian and vehicular.

The **general layout of physical properties** in an industrial plant or in any workplace is very important. From the safety standpoint, attention should be given to the location of pathways, roadways, and tracks, to the buildings and their relationship to one another, and to the locations of entrance and exit gates for pedestrian and vehicular traffic. In plants where employees walk on open roadways over which there is heavy vehicular traffic, studies should be made as to the advisability of providing tunnels and bridges.

The piling and storage of materials in plant yards should be in accordance with established procedures, particularly to keep materials from falling or protruding into open walkways and passageways.

MAINTENANCE AND PLANT HOUSEKEEPING.—The millwright and maintenance of equipment department should keep all machinery in first-class operating condition, but many times the safe condition of equipment is forgotten or at least put in second place. It is the job of the safety department and management to bring forcefully to the attention of such departments the necessity of keeping all equipment in a safe condition, but the matter cannot be left entirely to their care without the added precaution of a definite check by a group of their own personnel, or by plant safety committee members or the safety department itself. In a well-formulated plan of plant housekeeping, such a program should accomplish three objectives: first, the elimination of accident and fire hazards; second, the conservation of space, time, material and effort; and third, the improvement of employee morale.

Statistics show that a high proportion of industrial accidents are directly traceable to falls, falling objects, and mishandling materials, and that such accidents are often a direct result of disorder in the plant. Therefore, the problem of industrial housekeeping is a major one, and in the interests of safety, morale, and efficiency it requires careful consideration.

Good housekeeping has often been summarized by the phrase "A place for everything and everything in its place." If management fails to provide the "place," the employee finds adherence to this principle impossible. Providing the "place" should be carried out in its broadest sense. The start of a good program is an analysis of physical plant facilities, and a determination of the adequacy of existing equipment, such as shelves, bins, storage rooms, working places, and the like.

Building Maintenance.—Stairways should be kept clear of all materials, and should be properly illuminated. Accidents from tripping and falling are more likely to occur in these locations than on level surfaces. To comply with fire regulations, as well as good safety procedure, handrails of suitable height should be provided.

Aisles and passageways should be kept clear at all times for the safety of pedestrian traffic and trucks. Materials should not be permitted to project into aisles, and the latter should be clearly marked off, either by painted lines, inlaid tile, or other method.

Floors should be kept free from holes, uneven boards and obstructions, especially where the floors form parts of aisles or walking places. Materials used in floors should be considered from the safety standpoint in the erection of new buildings or in repair of old structures. Small objects, such as scraps of metal, nails, tools, etc., should not be allowed to lie on the floors or in passageways. Oil, grease, chips, and other sources of hazards which could be the cause of slipping or falling should be promptly removed.

All unnecessary hangings and trappings on walls should be removed. Windows should be in good working order, panes clean, and those cracked or broken replaced. Ceilings should be inspected for loose plaster, and skylights kept clean and in good order.

Inadequately illuminated workplaces are breeding grounds for bad housekeeping. All work benches, aisleways, and stairways should be suitably lighted and free from shadows. Night lights should be provided throughout departments so that watchmen will not be exposed to tripping and falling accidents. Exit lights should be placed at all emergency doors

and exits. The location of firefighting apparatus should also be suitably illuminated.

Waste cans with self-closing covers should be provided to hold cotton waste in each machine department. Two cans should be at each location, one for clean, and the other for soiled waste.

Proper operation and maintenance of **elevator equipment** are essential factors in a good housekeeping program. The storage of any kind of material in elevators should be prohibited and floors should be kept clear of debris. Elevators which do not stop level with factory floors create a tripping hazard. Elevators should be equipped with interlocking devices, which will prevent them from leaving landings while gates are open. Serious accidents have resulted from employees opening hoistway doors, expecting to find elevators at floor level, and falling down the shaft as a result.

Tool Cribs and Storerooms.—Convenient and well-maintained tool cribs are important. Small hand tools and implements should not be permitted to lie about where they may be the cause of slipping or tripping accidents. Special tool houses or rooms for picks, shovels, trowels, and similar implements for excavation and construction work may be provided. Some companies provide tool drawers and shelves for both outside and inside jobs. When these storage places are located conveniently, employees will use them, and the temptation to leave equipment around at workplaces where it would cause accidents, or be lost, is greatly reduced.

Improper piling or **storage of materials** is a major evidence of poor housekeeping. Only enough materials should be in the operating departments to keep production going. Raw materials should be brought in from the storeroom as needs arise, and in no greater quantity than is necessary. A minimum of material in the operating departments—just sufficient to keep an even flow of production—promotes both efficiency and safety.

In the storage of bulky objects, such as rods, pipe, lumber, and the like, many companies provide specially designed racks or guards to prevent the material from shifting and falling or rolling into aisles or places where men may be working. Small-sized material is usually put on shelves or in bins.

Awards for Plant Housekeeping.—Many companies have found the promotion of a competitive spirit among employees an important factor in the good housekeeping program. Sometimes tangible awards or recognitions are given to individuals and departments for good housekeeping, as an adjunct to awards for good safety records.

Safety Inspections

OBJECTIVES OF INSPECTIONS.—Safety inspections are one of the principal means of locating accident causes. They assist in determining what safeguarding is necessary to eliminate or otherwise remove hazards before accidents and personal injuries occur. Prompt safe-

guarding of hazards is one of the best methods for management to demonstrate to employees its interest and sincerity in accident prevention work. Inspections, however, should not be limited to unsafe physical conditions, but should include unsafe practices. One company recommends that for each inspection made for unsafe conditions three should be made for unsafe practices.

At the same time it should be remembered that safety inspections are not primarily to find how many things are wrong, but rather to determine if everything is satisfactory. The whole purpose should be one of helpfulness in discovering conditions which, corrected, will bring the plant up to accepted and approved standards, and result in making a safer and more helpful place in which to work, one where the working environment is such that operations can be conducted economically, efficiently, and safely.

SCHEDULE OF INSPECTIONS.—It is best to plan regular inspections to be made on schedule at definite periods, so that safety conditions are maintained at a high standard throughout the plant. Surveys should include all **means of egress** from the building. All exits, fire towers, fire escapes, halls, fire alarm systems, emergency lighting systems, and places seldom used should be thoroughly inspected to determine their adequacy and readiness for emergency use.

Another kind of periodic inspection is that **required by state and local laws**. These regulations include the inspection at regular intervals of elevators, boilers, unfired pressure vessels, and other special hazards. Such equipment, however, is not usually inspected by plant employees but often by outside inspectors, perhaps from casualty insurance companies, because of the special training necessary to qualify for this type of work. It is necessary, however, to follow a prearranged schedule of inspections as required by law.

Chains, cables, ropes, and other equipment subject to severe strain in handling heavy materials should be inspected at regular intervals, and a careful record kept of each inspection. Some state regulations require such inspections and records. This type of equipment should be stenciled or otherwise marked for ease of identification. Some companies require that all portable electric tools and extension cords be sent to the electrical department, say, between the first and tenth of each month. The electrical department inspects the tools, makes necessary repairs, and attaches a colored tag to the tool or cord showing the month the equipment was last inspected. A different colored tag is used for each month. Any tool or cord found without the proper tag is sent to the electrical department at once.

Other types of equipment, such as **cranes, hoists, presses, ladders, and power trucks**, require periodic inspection. Any equipment used in the field also requires frequent and periodic inspections. Such inspections should be ordered by the proper plant executives and the safety director should prepare a working schedule so that the correct intervals of inspection can be maintained.

Along with scheduled inspections, a careful survey should be made as to the **adequacy and safety of equipment in the plant**. Recommendations should be made for replacement of defective and obsolete equipment, as well as the purchase of any additional equipment that may be necessary. Such recommendations should be followed up until the changes are com-

pleted. As new processes and products are added to the manufacturing system, inspections may show that new accident or fire hazards may be introduced that require individual treatment; for example, special extinguishing devices.

One of the common kinds of inspections is that made at **intermittent intervals**, as the need arises, including unannounced inspections of particular departments, pieces of equipment, or small work areas. Such inspections made by the safety department tend to keep the supervisory staff alert to find and correct unsafe conditions before they are spotted by the safety inspector.

INSPECTIONS TO ELIMINATE SPECIAL HAZARDS.—The need for intermittent inspections is frequently indicated by accident tabulations and analysis. Should the analysis show an unusual number of accidents for a particular department or location, or an increase in certain kinds of injuries, special inspections should be made to determine the reasons for the increase and what must be done to remove the hazards.

In preparing for an inspection, it is advisable to **analyze all accidents for the past several years** so that special attention can be given those conditions and those locations known to be accident producers. Where accurate accident statistics are kept, such data are usually available in monthly and annual reports. Wherever an accident has occurred, it may take place again unless the unsafe condition has been corrected. Experience gained in correcting a hazard at one location will be helpful in safeguarding similar conditions in other locations. Inspections should not be confined to those places where serious injuries have occurred. Even no-injury accidents and near-accidents will often point to causes of possible future injuries.

Wherever there is a **suspected health hazard**, a special inspection should be made to determine the extent of the hazard and what precaution or mechanical safeguarding is necessary to provide and maintain safe conditions. These inspections usually require air sampling for the presence of toxic fumes, gases, and dust, testing of materials for toxic properties, or the testing of ventilation and exhaust systems for efficiency of operation.

SAFETY INSPECTORS.—The number of safety inspectors in any plant depends a great deal on the size of the plant and the kind of industry. Large plants with well-organized accident-prevention programs usually employ a staff of full-time inspectors who work directly under the safety supervisor. Large plants may also have a number of specially designated employees who spend part of their time on inspections. Also, there are usually employee inspection committees which assist in this kind of work.

Plants too small to employ a fulltime safety director and assistant inspectors depend a great deal on inspections made by maintenance men and supervisors. Frequently, an employee carries out the duties of a safety director on a part-time basis and makes periodic inspections. Many plants depend entirely on inspection service supplied by casualty insurance inspectors and also state factory inspectors. More frequent inspections, however, are usually necessary than are provided by these agencies.

Purchasing Safe Equipment

COOPERATION WITH THE PURCHASING AGENT.—Cooperation between the safety director and the purchasing agent is important. The purchasing agent is not concerned with the educational and enforcement activities of safety but he is with its engineering activities. It is his duty to purchase the various items of machinery, tools, equipment, and materials used in the establishment, and it is his responsibility —at least in part, and often to a considerable degree—to see that safety receives adequate attention in all purchases.

For this purpose he should be familiar with the workplaces and processes as well as the hazards of plant departments. He will want to know where and why accidents are happening and whether or not machinery, tools, or materials are at fault. He will not undertake to purchase any article until he has a thorough knowledge of its strength and work efficiency, and whether it can be used by the workers with the highest possible degree of safety.

Unsuspected Hazards in Purchased Items.—It is surprising to find that many items have a more important bearing upon safety than would be at first suspected. Particular attention should be given to the purchase of all personal protective equipment, all equipment provided for the movement of suspended loads, or for the movement and storage of materials, all miscellaneous substances and fluids used for processing which might constitute or increase a fire or health hazard, and similar items. But investigation also will show that unsuspected hazards may lie in very ordinary items, such as the commonest kinds of hand tools, tool racks, cleanings rags, the types of paint to be applied to shop walls and machinery, reflectors, and even bill files. Characteristics such as maximum load strength, long life without deterioration, sharp, rough, or pointed surfaces or edges, the need for frequent adjustment, ease of maintenance, effect of fatigue upon the employees, and hazards to the workers' health are among the many factors requiring attention.

The following are a few examples of hazards attending purchased items that were thought to be safe. Because a small hammer had been improperly annealed, a man's eye was lost when a piece of metal from its head flew 20 feet and struck him as he sat before his own well-guarded machine. Goggles supplied to one group of workers were found to have such imperfections in the lenses that they caused eye strain and headache, which led to fatigue and accidents. The toes of a laborer were crushed when the safety shoe he was wearing had an inferior cap and collapsed under a weight that should have been supported easily by a well-made shoe.

SAFEGUARDS ON NEW EQUIPMENT.—When an order is about to be placed for equipment, the purchasing agent who cooperates with the safety director will not consider any machine that has been only partly guarded by the manufacturer and that therefore will have to be fitted with makeshift safeguards after it has been installed. He will also be particularly careful to see that any purchased machine complies fully with the safety regulations of the state in which it is to be operated, for safety requirements vary widely in different states. The safety man will

assist in every way to make tests on new equipment, and, in fact, periodic checks on regular equipment, to assure the highest degree of safety by making sure that the best equipment available is being utilized. Many times it will be discovered that special equipment such as safety pliers, tongs, tweezers, stands for holding portable tools, spark curtains, etc., are not readily available on the market, and much time may be lost by having them made specially by outside firms. By close contact between safety department and mechanical departments, many such devices can be made in the plant in a few hours, thus removing the hazard and in many cases maintaining production which otherwise would be at a standstill. All safety equipment, and, in fact, all machinery to which safety equipment has been attached at the suggestion of the safety director, should be carefully tested by, or in the presence of, the safety director and the mechanical division before it is released for production. Where portable tools (pliers, tweezers, etc.) are provided, they should be systematically followed up by the safety man to check on their performance from the standpoint of safety.

Study and Analysis of Accidents

ACCIDENT INVESTIGATION.—Accident investigation is of prime importance. Its purpose should be definitely to develop better means for carrying on an accident prevention program. Otherwise, as fast as one accident hazard is detected and removed, another hazard may develop and eventually result in an accident of even greater proportions.

In most organizations an investigation of some kind is made of each accident resulting in death or injury to an employee. However, accidents which might have caused death or personal injury but which by a stroke of luck did not harm anyone, often are unreported, or when they are reported are rarely investigated.

Members of the National Safety Council, who make a practice of investigating all accidents, claim there is no more justification for assuming that a noninjury accident will not hurt anyone if it happens again than there is in drawing the same conclusion regarding an accident involving personal injury or death. They operate on the theory that there may be another "horse" and therefore a real necessity for "locking the barn."

Purposes of Investigation.—The principal purposes of an accident investigation are:

1. To ascertain the cause or causes so that measures may be taken to prevent similar accidents. These measures may include mechanical improvements, better supervision, instruction of workmen, and sometimes discipline of the person found guilty.
2. To secure publicity among the workmen and their supervisors for the particular hazard, and for accident prevention in general by directing attention to the accident, its causes and results.
3. To ascertain facts bearing on legal liability. Investigations for this object only, however, will not always suffice for future accident prevention purposes. But an investigation for preventive purposes may disclose facts that are important in determining liability. In this discussion the investigation is considered from the standpoint of safety, not liability.

Making the Investigation.—Depending on the importance of the accident and other conditions, the investigation may be made by one or more of the following persons or groups:

1. The foreman.
2. The safety engineer or inspector.
3. The workmen's safety committee.
4. The general safety committee.
5. A court of inquiry, board of inquiry, or jury.
6. In accidents involving special features it is often advantageous to call in an engineer from the insurance or state department to assist.

Each investigation should be made as soon after the accident as possible. A delay of even a few hours may permit important evidence to be destroyed or removed, intentionally or unintentionally. The results of the inquiry should also be made known quickly, as their publicity value in the safety education of workmen and supervisors is greatly increased by promptness.

Fairness is an absolute essential. The value of the investigation is largely destroyed if there is any suspicion that its purpose or result is to "whitewash" anyone or to "pass the buck." A "verdict" which places the blame on the workman, especially on the man who was injured, is likely to be scoffed at unless the personnel of the committee or jury arriving at the decision includes a generous proportion of fellow workmen having good standing among their associates. Perhaps even more important is the attitude of the safety department or other company representatives in making the inquiry. No one should be assigned to this work unless he has earned a reputation for fairness and is tactful in gathering the evidence. No browbeating of witnesses, either in private inquiry or in public, should be tolerated.

An accident causing death or some serious injury should obviously be investigated, but the near-accident that might have caused death or serious injury is equally important from the safety standpoint. Any epidemic of accidental injuries demands immediate special study. A particle of emery in the eye, or a scratch from handling sheet metal, may be a very simple case. The immediate cause is obvious, and the loss of time may not exceed a few minutes, but if cases of this or any other kind occur frequently in the plant or in any one department, an investigation should be made to determine the underlying causes.

There has always been confusion in the terminology used in reporting and analyzing accidents. Listed under "causes" are slips and falls, burns, slivers, punch presses, and other miscellaneous designations. These terms are used without regard for their correct meaning. Such misuse of words greatly reduces the value of accident records and causes confusion in prevention work. Detailed information on the plan and forms recommended for the purpose of collecting and analyzing accidental injuries to industrial employees should be in possession of the safety director (Safe Practices Pamphlet 21, Standard Industrial Injury Reporting System, National Safety Council).

INVESTIGATION PROCEDURES.—One company's procedure in the investigation of accidents covers such questions as: What happened? Why did it happen? How can a similar occurrence be prevented?

Four important steps are taken immediately after the accident occurs:

1. **The safety department makes an immediate preliminary investigation at the scene of the accident, to get all the facts.**

2. Later, as an intermediate step, the job is analyzed carefully.
3. A formal investigation is made by a committee composed of the manager or his assistant, an employee, an observer, and the safety engineer, whose duty it is to assemble all the facts and place responsibility.
4. Recommendations are later made by the safety department to prevent recurrence of the accident.

Preliminary investigation.

1. The first-aid records are consulted to determine: what happened, what the employee was doing, where he was working.
2. The safety engineer goes to the scene of the accident, questions all the workers in the area, takes pictures of all conditions.
3. The injured man is interviewed at once if his condition permits, to get his story before he has a chance to change it.

Intermediate investigation.

1. The injured man is again questioned to detect any change in his story.
2. A detailed study of the work methods of men on similar jobs and a study of similar equipment is made.
3. A study of the experience of other companies in similar cases is also made.
4. An investigation is made of the safety appliances in use.
5. The safety record of the injured man and his foreman is checked.

Formal investigation.

1. A meeting is held in the main office to establish in the mind of the employee that management is interested.
2. The investigating group is composed of the general superintendent, employee representative, and a foreman in the same line of work, chosen by the safety man. The safety man assumes the chairmanship, questions the witnesses, and then presents the evidence.

Follow-up by the safety department.

1. Reports of the investigation are sent to the department heads of similar departments.
2. Suggestions to correct similar conditions in other departments are submitted.
3. The report, in general, is publicized.
4. Related operations to detect similar hazards that may result in an accident are studied.
5. The accident is used as a subject for discussion in foremen's meetings.
6. A special bulletin is published each month listing all accidents.
7. A tickler system is used to follow up recommendations and see that they have been put into effect.
8. An exchange of accident experiences is carried on with other similar industries.

Maintaining Accident Records and Reports

RECORDS OF INJURIES.—Successful accident prevention by an employer in behalf of his employees requires a good system of recording accidental injuries. No modern executive would expect profits without adequate records of production, costs, and sales. Accident records serve a similar purpose for safety.

LOST TIME FREQUENCY AND SEVERITY RATE REPORT

Dept.__________
Supt.__________

WEEKLY Period Ending October 31, 19

Standing	Department	Man Hours Worked	Average No. of Men	No. of Lost Time Accidents	Man Days Charged	FREQUENCY Year to Date Thru This Week	FREQUENCY Year to Date Thru Last Week	FREQUENCY Decrease or Increase	SEVERITY Year to Date Thru This Week	SEVERITY Year to Date Thru Last Week	SEVERITY Decrease or Increase
1	Machinist	72402	1385	0	0	3.2	3.2	0	.59	.60	.01
2	2-AGL	36992	840	0	0	3.8	3.9	.1	.05	.05	0
3	Inspection	31886	732	0	0	4.2	4.3	.1	.024	.025	.001
4	4-AGL	29847	691	0	0	2.1	2.2	.1	.004	.004	0
5	N. Dept.	27595	662	0	0	21.2	21.8	.6	.44	.45	.01
6	Storeroom	22547	484	0	0	9.6	9.9	.3	.07	.07	0
7	Truckers	21789	508	0	0	11.2	11.6	.4	.09	.09	0
21	Tryout-5	4354	89	0	0	20.0	20.5	.5	1.6	1.7	.1
22	Salvage	3432	80	0	0	0	0	0	0	0	0
23	Pattern	3281	75	0	0	6.9	7.1	.2	.04	.04	0
24	S-1 Press	3021	68	0	0	17.7	18.0	.3	1.0	1.0	0
25	Tryout-3	2465	53	0	0	0	0	0	0	0	0
26	Tryout-2	2292	48	0	0	10.2	10.4	.2	.20	.21	.01
27	Shipping-5	2026	41	0	0	15.2	15.7	.5	.08	.08	0
28	Shipping-2	750	17	0	0	0	0	0	0	0	0
29	Shipping-3	85	2	0	0	0	0	0	0	0	0
30	S-1 Assy.	0	0	0	0	0	0	0	0	0	0
31	Millwright	28009	565	1	1	8.1	7.5	.6*	.04	.04	0
32	3-AGL	23288	513	1	6	12.0	11.2	.8*	.19	.19	0
	All Others	98388	2179	0	0	5.1	5.3	.2	.05	.05	0
	PLANT TOTAL	627295	13894	2	7	6.4	6.5	.1	.23	.24	.01

* Increase

FIG. 15. Weekly Lost-Time and Severity Rate Report for Department Heads

The following are some specific uses of accident records:

1. To disclose the departments, occupations, and individuals with the worst injury records.
2. To show the kinds of injuries that occur most frequently.
3. To permit accurate judgments on the most frequent accident causes.
4. To permit comparisons with previous periods, thus showing whether the accident record is getting better or worse.
5. To help secure the cooperation and interest of supervisors and workmen in safety.
6. To judge the general effectiveness of the safety program by comparison with other establishments.
7. To enable the safety engineer and the executive to carry out an accident prevention program without wasted effort.

To permit the above uses of accident data, a written record should be kept of the causes, circumstances, and consequences of each accident.

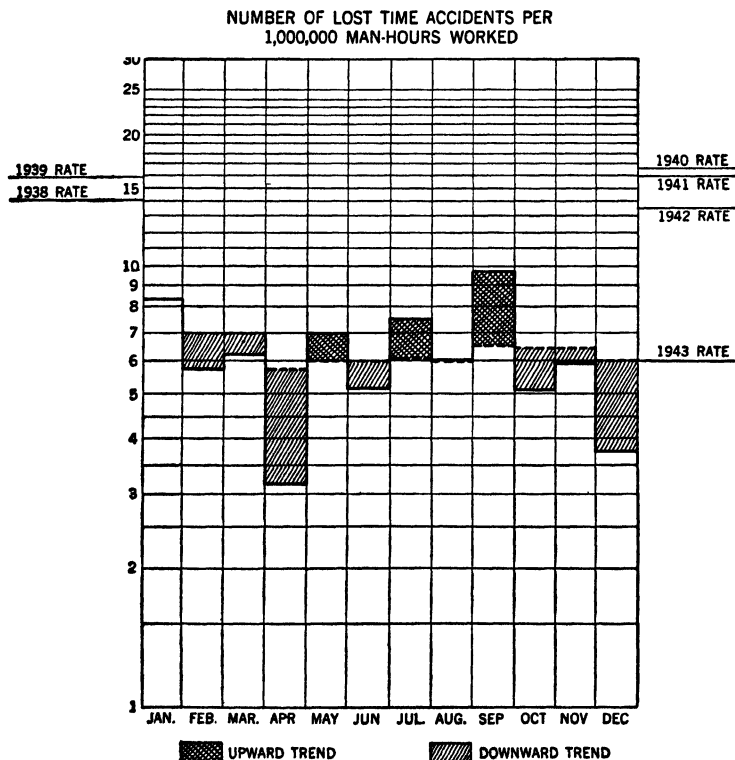



FIG. 16. Lost-Time Accident Frequency Rate Chart

Plotted monthly for current year with green sectioning for decreases and red for increases.

These reports should be periodically summarized and interpreted. It is not enough to record the facts on each individual accident. Unless these facts are summarized and significant comparisons made, the real value of keeping records is missed and the time and money spent are largely wasted.

Nondisabling Injuries.—A careful record must be kept of nondisabling injuries, however, because it is often only a matter of chance that they were not more serious, and their circumstances are usually similar to those resulting in major injuries. An analysis of the circumstances of these minor accidents, therefore, may be exceedingly valuable in finding out accident causes and correcting them. A large number of nondisabling injuries must always be viewed with concern because, sooner or later, the circumstances surrounding them are likely to produce serious results. Furthermore, the employee is being paid while receiving treatment for minor injuries and the company desires to know the cost of such treat-

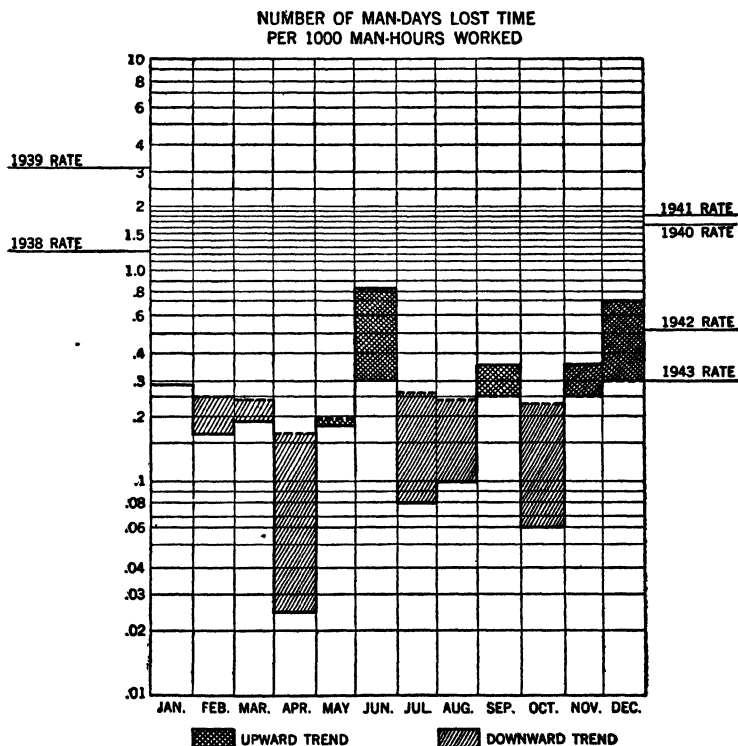



FIG. 17. Lost-Time Accident Severity Rate Chart

ments. It is desirable also to record first-aid injuries because they may develop later into serious cases and sometimes false claims for compensation. A standard method for keeping such records is a valuable aid in accident prevention work and in comparing results with other companies. (Standard Industrial Injury Reporting System, Pamphlet 2, National Safety Council).

ACCIDENT REPORTS.—Accident reporting forms, of which Fig. 15 is an example, which are sent to foremen, superintendents, and management, should convey the information most desired to assist in the determination of facts without needless detail. The production executive wishes to learn from accident reports which persons have accidents, in which departments they occur, how severe they are, and who is responsible. Again, he wishes to find out from other reports the cost of such unnecessary losses, and the reporting departments should present this information clearly and concisely.

Monthly progress reports on safety, summarized from department reports, are seldom laid aside by an executive without study and resulting comments. Color charts of the progress in terms of accident frequency and severity are helpful to indicate the rise or fall of plant experience, and at a glance he obtains the entire picture.

A yearly study of all accidents reduced to an intelligible report is also important. Such a summary, together with a complete analysis of the year's cost, will clearly define the progress and saving or loss from the efforts of those responsible for the safety activity of the plant. Typical charts showing comparative yearly records are shown in Figs. 16 and 17.

Company	% Reduction in Accident Frequency	Average Number of Employees
Chevrolet Motor Car Co. (Janesville Plant)	38	634
L. C. Smith & Corona Typewriter Co.	58	1,255
Victor Chemical Works (Acid Plant)	83	226
Deere & Co. (East Moline)	55	1,450
Jones & Laughlin Steel Co. (Aliquippa Works)	65	10,016
Humble Oil & Refining Co.	27	11,175
Wagner Electric Corp.	57	1,790
Addressograph Co.	39	1,000
Pennsylvania Rubber Co.	53	1,187
Dolphin Jute Mill	55	537
Eddystone Manufacturing Co.	67	709

FIG. 18. Reductions in Accident Frequency in Typical Companies During a Year

The representative reductions made by plants like those listed in Fig. 18 are significant. The production executive will look for the name of his own plant, or question its absence.

Most Accidents Are Preventable.—Records and reports show that more than 90% of all accidents are of a preventable kind, and that the majority of these accidents are due, wholly or in part, to man-failure in common forms, practically all susceptible of control through the exercise of proper supervision. Safety engineers must know **why** and **how** accidents occur, they must know the **causes** of accidents and direct their attack to the removal of those causes, instead of blindly and arbitrarily

selecting some expedient as a remedy. Elaborate, expensive, or experimental methods are not required, but only good management, careful supervision, and good engineering, such as are nowadays applied to maintaining quality and controlling production.

Industrial Relations

INDUSTRIAL RELATIONS PRINCIPLES.—Successful relations between employees and employers depend upon the recognition of definite principles. Charles R. Hook, President of the American Rolling Mill Co. (Principles Behind Employer-Employee Harmony, Nat. Assn. of Manufacturers pamphlet), states:

> No man can arbitrarily direct the work of the modern corporation successfully and happily. It is rather the collective and cooperative effort of the entire group associated together for a common purpose under general management direction.

He points out the fundamental necessity for written industrial relations policies so that the basis for dealings between management and workers may be clearly understood. Regarding collective bargaining he states:

> We have ignored the fundamental principle that whatever form best serves the mutual interests of labor, management, investment, and consumer is best! Collective bargaining used unfairly to extort conditions and advantages which are harmful to the enterprise upon which the employer and employee depend for their income is in the long run not only detrimental to the personal interests of both, but to the public interest as well.

Fundamental to sound dealings he emphasizes the training of supervisors to train workers; employee enlightenment on the various factors affecting their company, their jobs, and their earning power; the importance of community surroundings and influence; equitable distribution of the returns from production; promotions on merit; regularized employment; and recognition that the job is the center of the employee's universe, providing his family's livelihood, their home, their education, their recreation, and the other factors necessary for their existence.

From the standpoint of labor, Robert J. Watt, international representative, A. F. of L., expresses a similar approach. He says (A.M.A. Pers. Ser. 79):

> We must agree upon self-rule to the maximum through the delegated representatives of management and labor rather than by the rigid dogma of statutory law. We must operate through agreements among men, meeting practical problems by realistic adaptation of practical policies. If we fail, we will be confronted with the static blindness of rigid law and the directive of the dictator.

REGULATIONS GOVERNING INDUSTRIES.—Industrial legislation is not new but dates back at least 4,000 years, and for the more modern era began around 1770. While such legislation in recent years has been passed, at least in part, for restrictive reasons, many measures have a fundamentally sound and logical basis under conditions of increasing industrial expansion and growing complexity. Good legislation may:

1. Set good standards by which all concerned may be guided in their operations, especially where no industrial central agencies can undertake cooperative establishment of such standards.

2. Raise the minimum level of practice to that below which reputable manufacturers would not drop, for the good of their employees and the company.
3. Protect ethical manufacturers in the observance of such levels by fixing penalties for violations of the requirements.

Safety, health and sanitation, compensation for accidents, occupational diseases and deaths from industrial causes, unemployment insurance, fair labor practices, hours of work for women and minors, etc., are subjects of state legislation. The most important national legislation to obtain uniform practices throughout the United States includes:

1. National Labor Relations Act.
2. Fair Labor Standards Act.
3. Social Security Act.

DEMOCRATIC PROCEDURES.—Democratic methods designed to enable management and employees to participate in joint control of matters of mutual interest may be classified as follows:

1. Collective bargaining, usually in accordance with terms of a written agreement with a union to determine wages, hours, working conditions.
2. Union-management cooperation, designed to reduce waste, improve methods, increase sales, or otherwise promote best interests of organization.
3. Representation plan, works council, independent union within the company, or other plan intended to accomplish same purposes as (1) and (2) above.
4. Cooperation through labor-management or other committees, councils, or boards, or through occasional staff meetings, conferences, or less formal methods.

In all of these plans certain essential purposes or controlling objectives may be discerned when sound relationships exist:

1. To provide a means of collective dealing between employer and employees on wages, hours, working conditions, and other subjects of mutual interest.
2. To facilitate exchange of information and understanding between the supervisory and working forces.
3. To promote justice in relationships between workmen and supervisors.
4. To insure equitable consideration of grievances and complaints of employees.
5. To increase morale, contentment, and loyalty.
6. To furnish suitable facilities for constructive cooperation in furtherance of efficiency and economy of operation, thus promoting the success of the company.

COLLECTIVE BARGAINING.—Common usage confines the term "collective bargaining" to conferences or dealings covering wages, hours, and employment conditions, between management and organized labor, the basis for negotiation procedure being provided by a written agreement with the union. Very few companies attempt to negotiate on the basis of informal or verbal agreements.

The agreement may cover employees of a single craft or occupation, all or certain employees of one plant, several plants under one management, or several firms in a single industry. In some cases the widely separated plants of a company, even though manufacturing different products, and subject to divergent economic conditions, have been held by the N.L.R.B.

not to be appropriate collective bargaining units, a determination of fact placed by the Act itself under control of the N.L.R.B.

Similarly, office employees, chemists, engineers, inspectors, or assistant foremen may have little in common with the rank and file of factory workers and, under most conditions, cannot successfully be grouped with them for collective bargaining purposes.

In their dealings with management, employees are free—and protected completely from company domination—to select representatives of their own choosing, and may designate officials of the union or others who are not on payrolls of company.

Exclusive collective bargaining rights may be granted where 50% or more of the employees voting in an appropriate bargaining unit ask for some union or representation plan to act as sole bargaining agency. "Preferential agreements" grant preferred status to union members or to members in good standing, or give preference to union members in hiring, layoffs, or rehiring.

"Craft" unions are organized to include members of a single trade or occupation as distinguished from "industrial" unions, whose members include all eligible occupations in a plant or industry.

"Closed shop" contracts require union membership as a condition of employment for all, whether new or old employees, and also the "check-off" system of paying dues; whereas in "open shops" the employer exercises freedom of choice in selecting applicants, and employees may join unions or not, as they choose.

The National Labor Relations Act and official interpretations made under it permit employee representation plans or company unions, when not in any way employer influenced or dominated, as form of collective bargaining. It is significant, however, that a few large companies have withdrawn from some company union plans rather than risk prosecution for violation of the Act, and the C.I.O. in attempting to oust independent unions and supplant them with C.I.O. affiliates, brought many companies into court and forced a reorganization of the independent union along modified lines, if not actually succeeding in extinguishing it.

Collective Bargaining Agreements.—Indicative of the nature of collective bargaining agreements, an agreement between General Motors Corporation and the International Union United Automobile, Aircraft and Agricultural Implement Workers of America—C.I.O. may be cited. The divisions of this agreement cover:

1. Recognition
2. Representation
3. Grievance Procedure
4. Seniority
5. Disciplinary Layoffs and Discharges
6. Production Standards
7. Call-In Pay
8. Working Hours
9. Wage Payment Plans
10. Union Bulletin Boards
11. Establishment of New Plants
12. Wages
13. Leaves of Absence
14. Strikes, Stoppages, and Lockouts
15. Apprentices
16. General Provisions

The section relating to production standards in this agreement was formulated as follows:

Production standards shall be established on the basis of fairness and equity consistent with the quality of workmanship, efficiency of operations, and the reasonable working capacities of normal operation. The local Management of each plant has full authority to settle such matters.

When a dispute arises regarding standards established or changed by the Management, the complaint should be taken up with the foreman. If the dispute is not settled by the foreman, the committeeman for that district may, upon reporting to the foreman of the department involved, examine the job and the foreman or the time study man will furnish him with all of the facts of the case. If there is still a dispute after the committeeman has completed his examination, the foreman or the time study man will then reexamine the operations in detail with the committeeman on the job. If the matter is not adjusted at this stage it may be further appealed as provided in the Grievance Procedure.

Negotiation between unions and managements is somewhat outside the scope of a Production Handbook. The subject has received careful discussion in special works on personnel. A point emphasized by J. E. Walters (Personnel Relations—Their Application in a Democracy) is recognition of management, labor, the government, stockholders, and consumers as all being concerned, and the necessity, as well as the practical wisdom, of open-minded consideration of all points of view.

LABOR-MANAGEMENT COMMITTEES.—In the past few years labor-management committees were set up in a considerable number of plants. These committees were concerned mainly with matters of improvements in production and other betterment projects. Often they were limited to merely ordinary matters upon which workers and management could readily combine for temporary action. Where workers were members of unions, these committees performed no collective bargaining and handled no definite grievances, and generally they did not become bargaining agencies even when there was no union in the plant. One of their principal functions was to stimulate suggestions. Their effectiveness has been less than that of employee-representation plans, although their value where no such plan had been in effect has been considerable and in many cases they produced marked accomplishments. In some cases there were area councils of labor-management committees that held joint meetings to receive information through talks by speakers from local plants and to discuss ways of applying methods of various kinds in the individual units represented by the group.

Management and Labor Cooperation.—Indicative of the extent to which management-labor cooperation may be carried and prove constructive is the program planned for modernizing the New York dress industry, set up by agreement after a conference with employers on behalf of the Joint Board of the Dressmakers Union, International Ladies' Garment Workers' Union (Julius Hochman, General Manager of Joint Board, "Industry Planning Through Collective Bargaining"). This report and the subsequent developments actually indicated to the employer many steps which would make the industry more prosperous and, by inference, provide earnings out of which subsequent increases in wages could be granted.

Factors in Good Personnel Relations

MORALE IN INDUSTRIAL ORGANIZATIONS.—An aspect of factory organization that cannot be designed, written down, and visualized, but which is extremely important in operation, is sometimes called the unseen or informal organization. It comprehends the endowments, character, qualities, personalities, and social relations of the individuals

who form the organization personnel. If this **informal organization** is good, the whole will function with less friction and fewer conflicts than if it is bad. The unseen organization has a definite influence on morale.

Industrial morale has sometimes been defined as an **attitude or feeling toward the organization and fellow-workers** that affects the individual's relations to everything that he does. It is shown in the active desire of a member of an organization to participate resolutely, even at personal sacrifice, in efforts of his organization to achieve a determined objective. It need not affect, or be affected by, his conduct outside of the factory environment.

Many of those concerned with the subject, however, regard morale as something more fundamental than a mere attitude or feeling:

> Morale is a state of faith. In military, political, or industrial affairs it is essentially faith—in the organization, in its leadership, in its objectives, in the achievement of these objectives.
>
> Morale is personal in origin, for, as Napoleon said, "There is no such thing as a good regiment or bad regiment, but there is such a thing as a good or bad colonel." Organization morale thus operates from the top down. Only enlightened leadership in action can produce the esprit de corps that distinguishes the alert, aggressive, continuously advancing army, party, or business institution.

Le Roy H. Kurtz, Department of Public Relations, General Motors Corp., who offers this more comprehensive definition (The Morale Function of the Executive, Personnel, vol. 20, paper presented originally before the Society for the Promotion of Engineering Education), further explains the premise which he thus states by stressing the responsibility of the chief executive as the real morale officer of an organization, who, as a leader, must pave the way for the permeation of this quality throughout the whole personnel. Morale, he says, results from making proper demands upon people—"demands which enable them to win the psychological rewards of achievement. It connotes energy, eagerness, teamwork, success; lack of it is marked by confusion, apathy, muddling, and failure. . . . Leadership is the art of getting people in the right frame of mind to do their best. Morale is that quality of physical, mental, and spiritual fitness that demands release in action against the required objective."

Approach to the Morale Problem.—Within an industrial organization the problem of morale presents four phases:

1. Maintenance of industrial morale where it exists to a satisfactory degree.
2. Increase or intensification of industrial morale where it exists, but may be improved.
3. Creation of industrial morale where it is lacking.
4. Change or conversion of negative morale attitudes into those which are positive.

Before an attack can be made on this fourfold problem, the morale in the particular organization should be measured. Some promising attempts have been made to establish **indices of morale** derived from production, productivity, inspection, and cost reports. Each of these results or summaries of accomplishment in production is an integration of numerous continuously acting factors or forces, of which morale is one. Most of

these factors are relatively standardized, or at least their variations in a particular situation are not great and usually swing over a considerable period of time. These characteristics do not appear to apply to the factor of morale. Thus, whenever severe erratic fluctuations are discovered in indicated productive results, they may be traced to a change in morale rather than to other factors. A method of **diagnosis of industrial morale,** or attitudes, in industry consists in asking a series of questions, to be answered on a secret ballot. These queries are intended to reveal existence of positive and negative morale factors. This form of diagnosis appears at least to (1) segregate the working force into three groups—those who are satisfied, those who are dissatisfied, and those whose attitudes are indeterminate; and (2) secure some indication of causes of satisfaction and dissatisfaction.

Supervisory and Worker Morale.—Good morale as evidenced throughout the successive executive ranks in a plant is the necessary basis for a like spirit among supervisors and foremen. The latter, in turn, may engender the same spirit among workers, by prompt handling of complaints, dealing fairly with all workers, carefully interpreting and explaining any management regulations which may be causing unrest, and in other ways removing most of the causes of lost morale. On the other hand, if the foremen neglect such matters, or if their own morale is low, they may dampen the reactions of employees to the spirit of the enterprise and defeat the good work done by the management. Workers are also influenced in their morale by other workers whose attitudes toward the company are not cordial, perhaps because of some minor but nevertheless actual grievance. Morale cannot be forced. It must be induced. Unjust treatment, unwarranted severity, and many other acts on the part of foremen have considerable to do with the way workers feel and the loyalty they show toward the company. The right mental attitude of the worker depends on whether he is interested in his job, satisfied with it, and feels that his foreman is an able, trustworthy leader whom it is worth while to rally around and follow.

Low morale, if it exists among employees, has other results than merely a letdown in production. Workers will resent being given, and will avoid following, orders and instructions, task standards will not be met, quality will drop to a dangerous degree, accidents will occur more frequently, absenteeism will increase to an alarming extent, quits will become excessive and discharges more frequent, and the entire organization will get out of hand and refuse to respond to its executive heads.

Remedies for low morale in a working force are within the aims of labor, which include: good wages and steady income, proper hours of work, satisfactory work assignment, security of employment, good working conditions and surroundings, and equitable and impartial shop discipline and control. These objectives recognize the employees' continual hazards, such as accident, disease, unemployment, old age, and death.

It is the conviction of Elmo Roper, as a result of recent industrial surveys, that the worker's chief demands from his job are: (1) security by full employment at reasonably high wages, (2) a chance to advance; (3) "just to be treated like people," and (4) a feeling of dignity and responsibility (A.M.A. Pers. Ser. 72). These, the writer says, are more important to the employee than seniority or compulsory union membership.

Remedies for low morale in supervisory and managerial levels of organization are to:

1. Improve the organizational structure and functioning.
2. Improve personnel standards, with particular reference to qualities of leadership.
3. Maintain high morale in executive ranks. Toward this end ethical integrity should be unmistakable, courage should be present, action should be decisive, and enthusiasm should be imparted.
4. Stabilize administrative and managerial personnel.
5. Establish and maintain a high degree of coordination of effort at all levels of authority and degrees of responsibility.

Morale and the New Worker.—"From the very time he is hired a worker should be able to sense the morale of the organization and become imbued with the same spirit," says R. A. Sutermeister, Personnel Director, Pacific Huts, Inc. (Personnel, vol. 20). He further says:

Men enter an organization with a degree of pride and self-respect which spurs them to make good. What happens to the urge? The fact is that the urge to do a good job can be suppressed or killed by the treatment the worker receives. If it is suppressed, morale vanishes with it. Or management can adopt a negative attitude toward the new employee and do nothing about him. On the other hand, the natural desire of a man to do a good job can be stimulated and fostered, and if this is done morale can reach a high level. The destruction or encouragement of the desire depends on management and its personnel program.

The author of the above quotation states that in his company the follow-up policy lies in keeping open an intimate channel of communication between management and workers. The company employs less than 1,000 workers but has 15 full-time persons engaged in personnel work. Contacts are made in the afternoon with all workers hired in the morning, to find out whether the work suits them, whether it is too difficult, whether they would prefer to be on other work, and any other points which are important. The personnel director devotes at least one hour a day to talking with workers. At quitting time some member of the personnel staff is always at the gate to answer questions and clear up misunderstandings.

Stimulation by Special Effort.—One of the most extensive and spectacular drives to stimulate morale was the "Beat the Promise" campaign organized on a vast scale for all the RCA Manufacturing Co., Inc. plants, to stimulate production by dramatizing the entire effort. All the effective methods for promoting a huge drive were called into action: campaign dinners attended by shop stewards of the union and foremen, mass rallies of employees, speeches by executives and outside celebrities, spectacular exhibitions, buttons, slogans, banners, and awards. The objectives of doing better than the planned production schedule were achieved. Elmer C. Morse, Manager, Personnel Relations Division of the company, states (A.M.A. Pers. Ser. 55):

One thing bears repeating—that our successes are traceable to united and coordinated effort and active participation of representatives of union and management. I believe that men work for men and not for companies. The men who supervise our departments and the men who represent the unions in these departments are working together as co-captains toward our common objective. This unity makes possible our entire morale-building program. This unity insures the cooperative effort of all employees in

campaigns like "Beat the Promise." Such unity is industry's number one morale-builder.

Attitude Surveys.—A measure or evaluation of morale is given by attitude surveys, previously mentioned, which have been made in many companies in the effort to find out how workers and supervisors feel toward the organization by which they are employed. One such survey of 30 companies, made by Arthur Kolstad, Houser Associates (Attitudes of Employees and Their Supervisors, Personnel, vol. 20) showed that good morale among supervisors does not necessarily mean the same attitude among the workers, nor are the attitudes of supervisors in all cases more favorable than those of the workers. The questionnaires were somewhat similar for all the 30 companies, having a number of common items, and while separate forms were used for supervisors and for workers, many of the items were identical. Answers were written on the blanks at meetings of the two respective groups in each company, but with no executives present. The replies were secret and not signed or identified, and were placed by the employees in a special ballot box.

Typical results of the morale scores in the 30 companies, showing how the individuals rated the companies, are as follows:

Rank and file employees......	Low 58	High 80	Average 68.6
Supervisory staffs	Low 63	High 87	Average 75.6

Thirty-four per cent of all rank and file employees had morale scores above the average of supervisors.

Twenty-nine per cent of the supervisors had morale scores below the average of the rank and file.

Organization by organization, the largest positive difference between the two groups' ratings was 14 points (in 2 companies, where the ratings, respectively, were supervisors' average 74, rank and file 60, and supervisors' average 84, rank and file 70).

The largest "negative" difference was 6 points (supervisors 66, rank and file 72).

Correlation between supervisors and rank and file scores (Pearson coefficient) $+ .70 \pm .06$.

There was high correlation on the question:

In your opinion, are there other companies which treat their employees better than this one does?

( ) All the others are better.
( ) Most of the others are better.
( ) About the same.
( ) This company is better than most others.
( ) This company is best of all.

Proportions of supervisors endorsing this statement ranged from 48% to 96%; rank and file employees 29% to 94%.

On the point "When difficulties come up in my work I feel completely free about asking questions," the range of affirmative answers was supervisors 45% to 96%, workers 53% to 87%.

HANDLING GRIEVANCES.—So fundamental to harmonious operation is the prompt and satisfactory settling of grievances among workers that many companies are including training in this subject as a necessary part of preparing supervisors and foremen for the most effective operation of production departments. A grievance may be real or

imagined, hidden or open, an intentional affront or entirely innocent in origin, caused in the plant or occurring outside and coming to a head on the job, insignificant or major, strictly personal or related to the doing of work, happening at a time when the worker is in good humor or depressed and will take offense at almost anything. A small grievance, likewise, may be nursed into a big grievance as the employee thinks it over or is instigated by associates to make it an issue. Sometimes small grievances are fanned into flames by union representatives when wages, hours, concessions, closed-shop negotiations, and other moot questions are coming up for discussion and settlement.

The quickest and surest way to cure a grievance is to settle it when and where it occurs. The circumstances are usually known and therefore the causes may be corrected more readily. Moreover, prompt action to right the wrong, real or fancied, impresses the employee with the sincerity of the management on matters of fair treatment. Sometimes, however, it pays to let the matter rest until the offended employee has a chance to cool down and get control of himself. Both the conditions and the people involved must be carefully considered in taking or postponing action, and each case must be decided on its own merits.

Supervisors and foremen are in immediate charge of operations and therefore are at the focal point where most grievances arise. A better understanding of human nature and information on the fundamentals of adjusting grievances in the best way enables these key men to cure the grievances and correct the causes with the best chances of success. If the immediate cause is beyond the jurisdiction of the supervisor, he should call it to the attention of the superintendent or department head, or to whatever authority has been designated to handle the particular kind of matter. In some cases he may have to explain conditions to the employee and show him how the difficulty came about and what can be done to prevent its repetition. The Job Relations Training (J.R.T.) course of the Training Within Industry program, and foremen's conferences, are of great value in training the foreman to handle such a situation.

Counselors, as explained elsewhere in this Section, often come across grievances that have not been voiced or adjusted, but the counselors should work with, not against, the supervisor or other person to remove the cause. No counselor or member of the personnel department should encourage, or permit, workers to come and "cry on his shoulder" just to get favors or concessions, or evade regulations which the foremen in the line of authority are rightfully charged with applying.

Manual on Grievance Procedures.—The Western Electric Co., in the supervisory conference material of its Hawthorne Works training department, includes a most effective "Complaints and Grievances" pamphlet of 106 pages for the instruction of supervisors and foremen. This pamphlet explains the fundamental causes and remedies for grievances which may arise in the course of plant operation, making use of case material of a typical kind to qualify the supervisors better to learn the most effective procedures. The nature of the material presented is best illustrated by the section heads in the pamphlet:

1. A Statement of the Problem.
2. Complaints and Other Expressions of Dissatisfaction.
3. The Nature of Complaints.
4. Analyzing a Grievance.

DISCIPLINE CONTROL BOARD.—In the course of the innumerable contacts in an industrial plant there are sometimes unavoidable violent disagreements and serious or repeated violations of regulations. Department heads, supervisors, and foremen, if fair-minded, can and should handle most of those cases equitably and adjust the matter with workers on a mutually satisfactory basis. But there are instances where they find it necessary to have the trouble settled by more formal action because the case does not permit of ordinary measures, it may involve the need for official interpretation, or the supervisor feels that he cannot decide it in fairness himself. At Lever Brothers, R. W. Kelly set up a plan whereby a discipline control board handles such cases. The Allis-Chalmers Manufacturing Co. has adopted a successful similar plan whereby the discipline board takes over cases which call for more than foremen's warnings. (Arthur K. Brintnall, Chairman of Discipline Control Board, Fact. Mgt. & Maint., vol. 101). Two members of the personnel department, who keep records of the cases, are on the board—one, a psychologist, as chairman—and the superintendent and foreman of the employee in the case are the remaining members. A similar board was also set up to handle cases involving office employees.

The employee can state his side of the case in full because he knows he will receive impartial treatment and, if to blame, will be given a fair but not punitive penalty. The whole object is to check further similar violations by the employee involved or other employees. The foremen's authority is strengthened, they have no fear of being overruled, they feel that they are not forced to rely on their own judgment, they know that their disciplinary problems are taken seriously, and they are referring more and more cases to the board, 300 having been handled the first year. The foreman's traditional authority is maintained, cases are settled by calm judgment, not in the heat of the moment, warnings and penalties set by the board are uniform throughout the plant, employees have more regard for the necessary rules and regulations, and appeals may be taken by an employee or his union to the company's industrial relations review board and from there to an impartial referee. Such appeals have been at a minimum.

COUNSELING.—While supervisors and foremen are not excused from the duty of handling grievances and maintaining harmony in their working forces, the requirements of keeping production flowing and upgrading workers on their tasks cut down the time that they can devote to the complex personal problems of those under their direction. Moreover, foremen who are experts in operating methods and processes, good managers, and capable instructors, are not always well qualified from a psychological standpoint to aid in solving all the varied personal problems of their workers. In addition, there are problems which workers do not feel like discussing with foremen.

Personal friction, lowering of workers' morale from **unsatisfactory conditions** in the plant or because of home troubles, and other fundamental causes of upsets and often ultimate quits or discharges, are not only very costly but also seriously interrupt production schedules and disturb the working force throughout the entire department or plant. It is vitally necessary, therefore, to provide some adequate means whereby the inevitable upsets that cannot be directly taken care of by foremen can be handled promptly by other capable and understanding persons who will also impartially try for a fair and intelligent way to solve each case on its own individual merits. The counselor plan has been developed for this purpose.

A counselor receives his guidance and help from the personnel department but works to aid the foreman and cannot override the latter's authority, although he can point out matters which the foreman should correct, and he can indicate cases where a foreman seems incapable of dealing justly with his workers, or to maintain their loyalty and cooperation. The comprehensive nature of the functions of an employee counselor and the methods followed are well illustrated in a guide (prepared by William H. Kushnick, Director of Civilian Personnel and Training, War Department) from which the following discussion, in part, is summarized. The duties assigned are to:

1. Assist the employee in orienting himself to his work and associates.
2. Aid him in establishing satisfactory living and social arrangements.
3. Discover attitudes and reactions which prevent the employee from doing his best work, and aid him toward better conduct and attitude on the job.
4. Find out and refer to proper agencies the problems facing individual employees.
5. Search out poor working conditions and recommend improvements.
6. Aid supervisors in establishing the most helpful and harmonious relations with workers.
7. Assist in explaining management policies and practices to employees, and informing management of employees' reactions to such policies and practices.

There are certain **principles fundamental to a counseling program.** Counselors aim to help individuals to help themselves. They assist employees in solving problems which the latter cannot solve by themselves, or the foremen cannot answer. Information needed by counselors covers general data on the employees, familiarity with the plant, and a knowledge of community resources. Many problems must be discussed in privacy and suitable quarters are necessary for this purpose. Since the workers should consult first with supervisors on most questions, and will also have contacts with others, such as training instructors, safety men, various service agencies, the medical department, etc., counselors cooperate and have close relationships with these other persons, and with the management, and often may refer cases to them, or may advise the worker to consult a physician, lawyer, social agency, or other special authority. Preventive measures are superior to merely corrective expedients, so the counselor may often suggest improvements in company regulations, procedures, working conditions, and other factors which are potential causes of unrest or dissatisfaction. In all of his activities he will preserve as confidential the information disclosed to him by employees. If some action is necessary, he will not reveal the source or details of the complaint.

Procedures in Counseling.—In conference with employees the counselor should aim to:

1. Give the worker opportunity to "open up" and state what is on his mind.
2. Ask questions to develop all the facts.
3. Have the employee reason out his own solution of the problem if possible. Often he has not formulated the problem in his mind until he talks it over, and he sees the answer himself when he really understands what has perplexed him.
4. Adjust himself to the needs and convenience of the employee.
5. Ask for advice or suggestions, thus giving the worker self-confidence and gaining his cooperation.

Both men and women become excellent counselors. Sometimes a man will prefer to consult a woman counselor, or vice versa. Employees should be free to go to another counselor if the first one seems not to supply the desired advice, and they may go to one usually serving some other department if for any reason they do not wish to confer with the counselor in their own vicinity.

A Plant Counseling Program.—In one large manufacturing company, the counselors induct new employees—rather than having this service performed by the employment or training units—handle grievances and conduct termination interviews.

In the induction process they take a group of new workers to a classroom and check their names and buttons. Then they give out company handbooks and explain them. A brief tour of the plant follows on which all service rooms, first-aid stations, etc., are pointed out, and the general sequence of manufacturing operations in the areas concerned is shown. The employees then are separated into groups, women counselors for the women and men for the men, and directed to locker rooms, where, after uniforms are procured, the new employees change to working clothes. They are then taken to the timekeepers in their new work areas, receive time slips and are given an explanation of the time card regulations. Finally they are introduced to their respective department heads, who take charge of assigning them to their work. Later they are contacted by the counselor who carried on the induction, to see how they are progressing.

In hearing grievances and attempting solutions, all lengthy consultations are held in offices. Counselors are instructed to:

1. Listen and have the employee unburden himself and perhaps see his own answer.
2. Think out the problem and if a solution is not evident, discuss the matter with the chief counselor.
3. Wait if the problem requires more thought, but arrange, through the foreman, for the time and place to see the employee again.
4. Act to adjust the difficulty. Supervisors and foremen are expected to cooperate by putting reasonable recommendations into effect.
5. Report the action to the employee. Counselors, however, are not expected to play favorites or to fulfil unreasonable desires of employees.

In the solution of rate, pay, or production problems, counselors are instructed always to take the case to the supervisor or foreman but secure an answer. Where an employee is slipping badly, a counselor is called upon to answer the request of a foreman for aid in correcting such a failure. The counselor is instructed to:

1. Learn the facts from the foreman.
2. Visit the employee at his workplace, but without stating that he has any special occasion to talk with the worker.
3. Inquire casually as to his progress, work, and understanding of job, and try to find out if family troubles, personal ailments, or other outside causes are at fault.
4. Invite him for a conference if he begins to unburden himself of some difficulty.
5. Hunt the cause by indirect approach.
6. Reassure the worker by stressing the absolutely confidential nature of the talk.
7. Not give up if the cause is not readily found.
8. Find the reason of failure but not reveal the special nature of the conference.
9. Encourage the employee and act to aid him by the best means.
10. Check, follow up, and confer as often as necessary, with the employee, or chief counselor, to bring the case to a fortunate ending.

In connection with termination interviews, the counselor is guided by the following instructions:

1. Find out why the employee wishes to quit. Perhaps the cause may be corrected and he may stay.
2. Use reason, not pressure, in inducing him to change his mind. If the supervisor or foreman is the cause, a diplomatic approach to either may cure the trouble.
3. If he has bragged about quitting, he must be shown how he can keep his job, and still retain his prestige, or "save face," with his fellow-workers.
4. Do not recommend a raise, promotion, or similar change. These are matters for him to justify to his foreman by good performance later on his job.
5. See if a delay—say, a day off with the foreman's agreement—may not change the employee's mind.
6. Report the results to the personnel department.

While much of the work of counselors is routine, they must also aid in emergencies, such as where first-aid treatment is necessary, caution against safety rule violations by explaining reasons for the precautions adopted, and investigate absenteeism and lateness and help correct the cause, which is often thoughtlessness. Counseling aims to aid production and to help workers over difficulties associated with, or affecting, their working proficiency. It is not carried on to patronize workers or to permit them to gain advantages and concessions beyond reason in relation to their employment.

ECONOMIC COUNSELING.—A field of counseling which some industrial leaders think should be more widely available to employees, particularly to skilled workers, is that of assistance, when requested, with their personal business problems. John H. Goss, President and General Manager, Scovill Manufacturing Co., has long been an advocate of such counseling in employee relation programs. He points out that a few large industrial plants have such well-organized "economic health" services established through a section or a division of the comptroller's department, where the employee is free to go and ask for assistance, not only when he finds himself in difficulty, but also when he wishes advice and instructions as to how to keep himself from getting into difficulty. Mr. Goss emphasizes the point that the service is optional and, to be

successful, must be rendered in a spirit of absolute confidence which must never be abused. He considers that such counsel can be an important force in the development of human values, not only material, but those involved in the philosophy of relationships among men; and that education of workers in conducting their personal affairs on a responsible and businesslike basis has a direct relation to production and will prove an excellent builder of morale.

SUGGESTION PLANS.—The suggestion plan is a definite arrangement under which employees are invited to advance ideas for the improvement of methods, operations, equipment, materials, employee service, etc., and are rewarded for proposals that are accepted on these and related lines. Certain factors are important in setting up and operating such a plan:

1. The plan should be "sold," energetically and persistently, by the supervisors. Workers have to be continually stimulated to participate.
2. Suggestions should be considered seriously and impartially, by a committee so constituted as to command respect. When they are not adopted, specific reasons should be given.
3. Every precaution should be taken to prevent the suggestion of one person being credited to another, particularly if that other is a foreman or executive.
4. If **awards for suggestions** are in form of cash, there should be some visible relationship between value of suggestion and size of award. Paying $5 for an idea which saves a company $5,000 a year serves mainly to teach workmen to carry their suggestions to other markets. However, it should be made clear to employees that many suggestions become valuable only after they have been improved and made workable through the efforts of the company.
5. Suggestions, the values of which are intangible, may sometimes be recognized by a moderate money award and some additional acknowledgment other than cash, such as a special certificate.
6. Records of approved suggestions, even if the details are not available but only the fact of the award is known, should be placed in the employees' personnel folder.
7. Bulletin board notices and articles in plant publications, with announcements of awards and photographs of those whose suggestions were especially meritorious, are good methods of maintaining employees' interest and enthusiasm.

Savings from a Suggestion Plan.—The General Motors suggestion system, as described by T. P. Archer, Vice President in Charge of Manufacturing (A.M.A. Prod. Ser. 153) divides accepted suggestions into five classifications, with awards paid accordingly:

Class A. Suggestions relating to the employee's own job and which bring a saving of material or labor in current use, resulting in increased production above the standard established for the job. Award: value of savings in material and/or labor for a period of two months at the then prevailing production schedule. Maximum award, $1,000 face value bond.

Class B. Suggestions on operations done by the operator and others on this same work. In this case an operator offering a Class A suggestion will get not only his two months' savings award but also one month's savings of all the other employees on this duplicate operation. These other employees each get the savings on their operations for one month.

Class C. Suggestions resulting in improved quality or improved safety conditions, or matters not concerned with productive operation. Award: maximum of $23.75 payable in war bonds and stamps.
Class D. Suggestions like Class A, only made by an employee for other than his own job. Award: 50% of a two months' saving on labor and material. Maximum award: $1,000 face value bond. In addition, employees on the operation directly affected divide an award equal to 50% of the value of the actual labor savings over a period of two months. The suggestion committee decides the manner of division.
Class E. Suggestions not covered by Classes A, B, or D and not adequately rewarded under Class C. Award: recommended by suggestion committee, with due consideration to the benefits accruing from the suggestion. There is no limit on such awards.

Over a period of the first two years, eligible employees submitted 180,000 suggestions, of which 33,831 were accepted, or about 20% of the total reviewed, and $1,214,000 was paid out in actual awards. In one division over 350,000 man-hours were saved beginning from the time the suggestion plan was put in operation. In over 140 cases the $1,000 bond was awarded, over 450 awards of $500 or more were given, and over 2,200 awards went to women, two of them $1,000 awards.

PUBLIC RELATIONS ASPECTS OF PERSONNEL PROBLEMS.—Customers, as well as the general public, have a definite interest in a plant's labor policies. Wage levels, strikes, lockouts, sabotage, accidents, all interfere with the activities and interests of many outside of the plant affected. Public health standards are raised, and fire hazards may be reduced, by measures taken in a plant. Employment, layoffs of workers, retirement of pensioners, etc., affect local economic conditions. Plant efficiency determines the price of product; there is growing public recognition that the consumer finally pays the cost of lax and ineffective personnel procedures. When public relations in these respects are good, a better grade of applicants is secured, and pride in plant, organization, and product is enhanced.

INDEX

C

E

F

G

H

J

K

L

M

N

S

T

U

V